Survey Results of Green Sea Urchin (*Strongylocentrotus droebachiensis)* Populations in Queen Charlotte Strait, British Columbia, October, 2006

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SURVEY RESULTS OF GREEN SEA URCHIN (*Strongylocentrotus droebachiensis*) POPULATIONS IN QUEEN CHARLOTTE STRAIT, BRITISH COLUMBIA, OCTOBER, 2006

by

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ABSTRACT

Waddell, B. J., and Perry, R. I. 2007. Survey results of green sea urchin (*Strongylocentrotus droebachiensis*) populations in Queen Charlotte Strait, British Columbia, October, 2006. Can. Tech. Rep. Fish. Aquat. Sci. 2742: vii + 47 p.

This report presents the results of a green sea urchin (*Strongylocentrotus droebachiensis*) survey undertaken jointly between Fisheries and Oceans Canada (DFO) and industry (West Coast Green Urchin Association - WCGUA) in Queen Charlotte Strait, British Columbia, in October, 2006. This survey is part of a continuing series, starting in October, 1995, whose long-term objectives are to assess variability in green sea urchin populations, and to monitor impacts due to a commercial fishery. The survey was conducted prior to the opening of the commercial green sea urchin fishing season, and was undertaken at three sites, which included areas open or closed to commercial fishing. The survey was conducted by SCUBA divers, using the transect-quadrat method. Data were collected on size and abundance of green sea urchins, gonad weight and quality, and on the depth, substrate and vegetation; results are presented for three size classes of urchins.

The mean densities and biomasses of legal-sized green urchins at the commercially fished site (the Stephenson Islets) have fluctuated over the series of surveys, but have generally increased over time. During the present survey, the mean density and biomass of legal-sized ($\geq$ 55 mm test diameter (TD)) urchins increased from the previous survey (November, 2004), and were the second highest of all the surveys at this site. Similar results were observed for the sublegal-mature-sized (25 mm $\leq$ TD $<$ 55 mm) urchins. At one of the non-fished locations (Stubbs Island), the densities and biomasses of legal and sublegal-mature-sized urchins remained relatively high compared with previous surveys, while at the other location (Plumper Islands) these values generally decreased to more moderate levels. The mean densities and biomasses of immature (TD $<$ 25 mm) urchins at all three locations in October, 2006 were some of the lowest values observed over all the surveys, after being at the highest level at all three locations in the previous survey of November, 2004. This suggests recruitment of green sea urchins in this area may be low from spawning during the spring of 2006.

RÉSUMÉ

Waddell, B. J., and Perry, R. I. 2007. Survey results of green sea urchin (*Strongylocentrotus droebachiensis*) populations in Queen Charlotte Strait, British Columbia, October, 2006. Can. Tech. Rep. Fish. Aquat. Sci. 2742: vii + 47 p.

Nous présentons les résultats d'un relevé de l'oursin vert (*Strongylocentrotus droebachiensis*) mené conjointement par le ministère des Pêches et des Océans (MPO) et l'industrie (West Coast Green Urchin Association - WCGUA) dans le détroit de la Reine-Charlotte (C.-B.) en octobre 2006. Ce relevé s'inscrit dans le cadre d'une série de relevés qui a débuté en octobre 1995, dont les objectifs à long terme sont d'évaluer la variabilité des populations d'oursin vert et de surveiller les impacts de la pêche commerciale de cet échinoderme. Le relevé a été effectué avant l'ouverture de la saison de pêche commerciale à trois endroits, y compris des endroits où elle y a était autorisée et des endroits où elle y était interdite. Des plongeurs équipés de scaphandres autonomes ont utilisé la méthode des transects et des quadrats pour recueillir des données sur la taille et l'abondance des oursins verts, sur le poids et la qualité des gonades, ainsi que sur la profondeur, le substrat et le couvert végétal. Nous présentons les résultats obtenus pour trois classes de taille d'oursin.

La densité moyenne et la biomasse moyenne des oursins verts de taille réglementaire au lieu de pêche commerciale (îlots Stephenson) fluctuent au fil de la série de relevés, mais ces variables augmentent généralement au fil du temps. La densité moyenne et la biomasse moyenne des individus de taille réglementaire (diamètre du test $\geq$ 55 mm) au cours du présent relevé montrent une augmentation par rapport au relevé précédent (novembre 2004) et elles se classent au second rang en importance parmi toutes les valeurs enregistrées lors des relevés à cet endroit. Nous avons obtenu des résultats semblables pour les oursins matures de taille non réglementaire (25 mm $\leq$ diamètre du test < 55 mm). À un des lieux non exploités (île Stubbs), la densité et la biomasse des oursins matures de taille non réglementaire et de taille réglementaire demeurent relativement élevées par rapport à celles observées lors des relevés antérieurs. Cependant, à l'autre lieu non exploité (îles Plumper), ces variables ont en général baissé pour atteindre des niveaux plus modérés. La densité moyenne et la biomasse moyenne des oursins immatures (diamètre du test < 25 mm) aux trois endroits en octobre 2006 comptent parmi les valeurs les plus basses observées pour l'ensemble des relevés, après avoir été au niveau le plus haut pour les trois endroits lors du relevé précédent en novembre 2004, ce qui suggère que le recrutement de l'oursin vert dans ce secteur est faible en raison de la fraie au printemps 2006.

INTRODUCTION

The commercial green sea urchin (*Strongylocentrotus droebachiensis*) fishery has existed in British Columbia since 1987. It is of modest value, but is an important component of the suite of dive fisheries in B.C. Hand-picking by divers is the only method allowed to harvest this species. It is currently managed using a minimum size limit of 55 mm test diameter (TD), by restricting areas and fishing seasons (usually open from November until March or April), a limited entry licensing scheme, area quotas, and by an Individual Quota (IQ) system. Fishers are required, as a condition of licence, to complete harvest logbooks and charts and submit them to Fisheries and Oceans Canada (DFO). The logbooks contain information on the dates and locations that green urchins were caught, divers' names, how long fishing was conducted each day (i.e., effort), diving depths, and the total weight of urchins removed (i.e., catch). Up until 1996, these, along with sales slip data, were the only sources of B.C. data available upon which DFO stock assessments and management decisions were based. These data are of variable quality because of changes in fishing practices and the aggregating nature of green sea urchin distributions. The harvest logbooks also do not contain information on sublegal-sized urchins, size frequencies of the whole population, densities, roe quality and quantity, or habitat associations.

In order to obtain fishery-independent data, a survey protocol was developed to study interannual variability and the impacts of fishing on the green sea urchin populations. The survey design includes a site open to commercial harvesting (and fished most years) and two nearby sites closed to commercial fishing. Surveys were conducted in October, 1995 and March, 1996 (Waddell *et al.* 1997), November, 1996 and February, 1997 (Waddell *et al.* 2002), November, 1997 and March, 1998 (Waddell *et al.* 2003), November, 1998, 1999, 2000, 2001 and October, 2002 (Waddell and Perry 2005), and October, 2003 and November, 2004 (Waddell and Perry 2006) to obtain this crucial information. No survey was performed in the fall of 2005 due to budget constraints. By coordinating surveys that involved all parties with interests in the green sea urchin fishery, i.e., DFO, First Nations (first two years of surveys) and the commercial industry, there has been improved confidence and acceptance of these data. This current report presents the data collected from one cooperative survey performed by DFO and industry (West Coast Green Urchin Association or WCGUA) in October, 2006. An overview and interpretation of all of these surveys will be presented in a future paper.

The long-term objectives of these green sea urchin scientific surveys are to monitor population changes and to assess the impacts of the fishery on green sea urchin populations at a key fishery location. The data are also used in the stock assessments for this species. To meet these objectives, green sea urchin densities, size measurements, and samples for gonad quantity and quality were obtained, both in areas open and closed to commercial green sea urchin fishing, prior to the opening of the commercial fishery. All of the surveys have been conducted at the same location in Pacific Fisheries Management Area 12 (or PFMA 12 or Area 12, where the majority of the fishery occurs), in Queen Charlotte Strait, near Telegraph Cove (Figs. 1a-1c). The Stephenson Islets met the

criterion for the survey site open to commercial fishing because fishers have historically found this site to have consistently high numbers of legal-sized green sea urchins. Stubbs Island and the Plumper Islands met the criterion for monitoring population changes due to environmental variations, and are located close to the Stephenson Islets. Stubbs Island and the NW section of the Plumper Islands have been closed to commercial fishing (for research purposes) since the fall of 1995.

In the first three initial years of these surveys, (from fall 1995 to spring 1998), there was a survey just prior to the opening of the fishery (which was usually in mid-November), and then another survey shortly following the closure of the fishery (which was usually in mid-March). The length of the opening of the fishery in Area 12 varied from year to year, and was occasionally closed before the end of the season due to the fishers reaching the allowed quota for the area. Due to funding shortages and generally inclement weather in the spring, surveys carried out following the closure of the fishing season were discontinued after March, 1998. Surveys have been conducted every fall since 1995, except for the fall of 2005, when funding shortages again prevented the survey from being conducted. The survey discussed in this report is the first survey conducted since the cancellation of the fall 2005 survey, and was undertaken just prior to the opening of the commercial green sea urchin fishery.

METHODS

(a) DATA COLLECTION – FIELD AND LAB

The survey was performed from October 26-27, 2006. It was designed, organized and supervised by DFO, and the costs were supported by both DFO and industry. There were two dive teams (i.e., two boats), each with one industry and one DFO diver, one boat driver (industry or DFO), one dive tender (industry or DFO), and one observer/recorder (DFO). The vessels involved were the CFV '*Second Wind*', owned by an industry fisher, and the DFO vessel '*Pallasi*'. There were nine transects surveyed for green sea urchins in the Stephenson Islets (50°34.5' N, 126°49.5' W), at the north end of Johnstone Strait, near Telegraph Cove and Weynton Passage (Fig. 1b), two transects at nearby Stubbs Island (50°36.2' N, 126°49.2' W; Fig. 1c), and four transects in the Plumper Islands (50°34.6' N, 126°48.0' W; Fig. 1c). In the past there have been as many as ten transects surveyed at the Stephenson Islets, four transects at Stubbs Island, and six transects in the Plumper Islands. The dive teams attempted to survey all of the same transects as in the 13 previous surveys, however, strong winds, rough seas, and large numbers of sea lions prevented all of the transects from being surveyed this time.

The transect positions were randomly selected during the first survey in 1995 and marked on a chart prior to arriving at the survey area (Waddell *et al.* 1997, 2002). The transects ran perpendicular to the shoreline and/or depth contours (with slight adjustments of the angle to best manage the direction of the current), starting at 10.0 m (32.8 ft) below Chart Datum (CD) and continuing up to zero CD. A computer program called "Tides and Currents for Windows" (Nautical Software Inc. 1995) was used to calculate the tide levels for every five minutes so that the depth to CD could be determined before each

dive commenced. A weighted (lead) line was laid from shallow to deep to mark the transect, with a surface marker buoy indicating the deep end of the line. At the start of each transect, a compass bearing was taken by the divers from the marker buoy to the shallow end. Beginning at the deep end, the divers placed a 1 m^2 aluminum quadrat on the substrate beside the lead line and measured the test diameter (TD) (using calipers) of all green sea urchins within the quadrat, and counted all red (*Strongylocentrotus franciscanus*) and purple (*S. purpuratus*) sea urchins. All urchins were removed from the quadrat as they were being measured to avoid repeating measurements. An urchin was considered to be in a quadrat if one-half or more of its body was within the quadrat's boundaries. Sometimes green urchins were under vegetation, rocks, or in crevices, so all surfaces were explored in order to find all sea urchins. One diver did all of the measuring while the other diver recorded the data on waterproof paper. The depth, substrate and type of vegetation were also recorded for each quadrat, and then the quadrat frame was rolled over in the direction of the lead line (or the compass bearing when lead line could not be used), and the procedure was repeated along the full length of the transect.

The surface personnel recorded the position (using a GPS) for both the start and finish of the transects, as well as the divers' start and finish times for each transect (for use in calculating depth from CD), and the weather conditions.

Three green sea urchins of each of three size classes (small, medium and large) were randomly collected along the transect lines during the surveys for later laboratory analyses of size and weight and dissected to obtain roe quality information. In addition, another 10 urchins were randomly collected along the transect line for size and weight information only (i.e., not dissected). These latter samples were all measured on the same day as they were collected, whereas all of the other urchins were measured and dissected on the day following collection. For each of the dissected urchins, the following data were recorded: test diameter; test height; total wet weight; drained weight; gutted weight (stomach and contents removed); gonad weight, colour and texture; and sex. Gonad colour was given a qualitative rating code of 0 (unknown (i.e., missing), or no gonad present), 1 (orange/yellow), 2 (yellow with other colours), or 3 (brown/red). Gonad texture was also given a qualitative rating code of 0 (unknown (i.e., missing), or no gonad present), 1 (firm), 2 (semi-firm), and 3 (flimsy).

(b) DATA ANALYSES

Occasionally divers started surveying deeper than 10 m below CD, or they continued surveying shallower than 0 m CD. Since the area estimate for the Stephenson Islets is based on the area between the 0 and 10 m isobaths, and green urchins are usually sparse at depths greater than 10 m below CD, the divers' data were truncated to include only data collected between 0 and 10 m (33 ft) below CD for the overall density calculations, biomass, and for the density by substrate calculations. The original (unadjusted) data were used for all other calculations presented in this report.

Test diameter frequency distributions were analyzed using the computer software "MIX3aa" (Macdonald 1994) to identify dominant size modes under the assumption that individual modes were normally distributed (see Macdonald and Pitcher (1979), and

Macdonald and Green (1988), for details). In general, initial parameters (mean and standard deviation) were assigned by examination of test diameter frequency data distributions collected during the surveys at each site. The software "MIX3aa" was then used to estimate the proportions while keeping the mean and standard deviation parameters fixed. Next, estimates of mean, standard deviation, and proportion were calculated by varying the constraints on each until a reasonable fit to the data was established. This fit was determined by the goodness-of-fit chi-square statistical test and examination of the size frequency histogram with its fitted components. The software fit the means, proportions, and standard deviations of the size frequency distributions using the Quasi-Newton Algorithm technique (Macdonald and Green 1988). The test diameter frequency distributions were analyzed for data obtained at Stephenson Islets, Stubbs Island, and Plumper Islands.

In many of the analyses, the data have been separated into three different size classes: legal-sized (TD $\geq$ 55 mm); sublegal-mature (25 mm $\leq$ TD $<$ 55 mm); and sublegal-immature (or immature; TD $<$ 25 mm). The mature/immature size of 25 mm TD was approximated from the dissection roe quality and maturity data, in which 100% of green urchins $<$ 25 mm were immature (no gonad present) compared with 6% of urchins $\geq$ 25 mm being immature.

Mean and total densities of green urchins for each transect within each of the three survey sites (Stephenson Islets, Stubbs Island, and Plumper Island) were calculated as described by Jamieson and Schwarz (1998). These surveys are characterized by the quadrats within a transect not being independent (e.g. if one quadrat has a high number of urchins, then adjacent quadrats are likely to have high numbers as well), transect lengths vary among the transects, and all urchins within each transect are counted. These features indicate a "complete cluster" sampling design with unequal-sized clusters (Jamieson and Schwarz 1998). The appropriate calculation for the mean density (of a particular size class of urchins) is:

$$\overline{D} = \frac{\sum_{i=1}^{n} U_i}{\sum_{i=1}^{n} L_i} \qquad (1)$$

and for the standard error of density is:

$$SE(\overline{D}) = \sqrt{\frac{1}{\overline{L}^2}\frac{1}{n}\frac{\sum (U_i - L_i\overline{D})^2}{n-1}} \qquad (2)$$

with n = the number of transects sampled in a particular site;

U_i = the total number of urchins of the appropriate size class in transect i, $i = 1,2,\ldots,$

L_i = the total number of quadrats in transect i; and

$\overline{L}$ = $\frac{1}{n}\sum_{i=1}^{n} L_i$, the average area of the transects in the site.

Since the area of a quadrat was 1 m^2, L_i is also equal to the area of the transect.

In the results that follow, standard errors have not been calculated for the individual transects since the transect has been defined as the (cluster) sample unit, and therefore the (n-1) term in the denominator of the equation for the standard error goes to zero. In the calculation of urchin densities by depth range and substrate type, however, the quadrats have been considered as the sampling unit, and distributed among the various depth and substrate categories. This reduces (but does not entirely eliminate) the problem of non-independence among adjacent quadrats, and so standard errors about the mean densities for these classifications have been calculated using standard formulae (e.g. as found in Sokal and Rohlf (1981) and as implemented in the "EXCEL 2002" (Microsoft) statistical software package).

When calculating the "densities of green urchins by depth range", the actual depth below CD had to be determined for each quadrat, which depended on the continually changing tide height. The method for calculating this has changed slightly over the years. Initially, (Waddell *et al.* 1997, 2002, 2003), the mean tide height above CD over a transect was calculated and then this one mean value was subtracted from all of the depth gauge readings for that transect. It was then realized that sometimes the tide could change significantly over the length of a dive, especially if it took a long time to survey a transect. The method was changed (Waddell and Perry 2005, 2006) by first calculating the number of minutes spent at each tide height above CD (rounded feet) over the length of each transect, using the "Tides and Currents for Windows" program (Nautical Software Inc. 1995) set for every one minute. Then the tide height above CD was calculated for each quadrat by proportioning the dive time over the whole transect according to the number of quadrats in each transect. Once this was calculated, then the tide height above CD was subtracted from the depth gauge reading recorded for each quadrat, to give the approximate adjusted depth below CD. However, we realized that some quadrats would take longer than others to survey, especially ones that had high densities of urchins. Therefore, instead of proportioning the number of quadrats over the dive time at each tide height, we calculated the mean number of urchins measured per minute, and how much time was spent at each tide height. The number of urchins were then calculated for each tide height. By going through the datasheets and counting the number of urchins, we were able to estimate more accurately when (at which quadrat) the tide height would have changed. The tide height above CD was subtracted from the depth gauge reading recorded for each quadrat, to give the approximate adjusted depth below CD. Note that the depth readings are initially recorded in feet and then converted to meters for the report because the depth gauges only read in feet.

The three most abundant substrates in each quadrat were recorded, in order of prominence. The tables and figures in this report that display the substrate data use three digit codes that represent the order of prominence and type of substrates observed. A similar recording method was used for vegetation types. However, there are some problems associated with these latter data, making it difficult to interpret the results. Therefore vegetation data are not presented in this report.

The statistical software package "EXCEL 2002" (Microsoft) was used to find the best relationships (i.e. highest R^2) between TD (in millimeters) and the variables test

height (in millimeters), total wet weight (in grams), and gonad weight (in grams). These were calculated from dissection data for all sites combined, and for each of the three sites separately, for both of the surveys. The majority of the calculations had the best fit when the power equation was used (i.e., *variable* = $\alpha(TD)^{\beta}$), therefore this was the standard equation used for all calculations. Note that samples that had gonad weights of zero were removed from the calculations.

The mean abundance of green urchins was converted to total biomass for all of the survey sites using the mean individual urchin weights (separated into three size classes), the mean densities, and the total area of each site. Rather than using a single mean individual weight for the whole sample population to convert abundance to biomass (as in Waddell *et al.* 1997), we used the following method (as in Waddell *et al.* 2002, 2003, 2005, 2006). The measured green urchins were separated into three size classes: legal-sized (TD $\geq$ 55 mm); sublegal-mature (25 mm $\leq$ TD < 55 mm); and immature (TD < 25 mm). The individual weights were calculated for each urchin measured in the field survey using the TD-weight relationships derived from the laboratory measurements, then the mean individual urchin weight ($\overline{W}_j$) was calculated for each size class (j). The standard error about the mean weight for each size class (SE($\overline{W}_j$)) was determined by calculating the standard deviation of the mean weight and dividing by the square root of the sample size. A test for homogeneity of the regression slopes was performed to determine whether the TD and the natural log of the total wet weight relationship could be used for all sites combined (within each survey) or if the relationship for each site had to be used separately. This test was programmed in "EXCEL 2002" using equations from Zar (1984, p. 300).

The total biomass for a particular site was then calculated as

$$B = \sum_{j=1}^{3} \overline{D}_j (\overline{W}_j)(A) \tag{3}$$

where j subscripts the three size classes. The area (A) (from 0 to 10.0 m below CD) of each survey site was determined to be 485,200 m^2 for Stephenson Islets, 19,600 m^2 for Stubbs Island, and 223,600 m^2 for the Plumper Islands, based on a geographic information program called COMPUGRID (Geo-Spatial Systems Ltd. 1996).

The standard error of the total biomass for a particular site, which includes the uncertainties in the mean density and mean weight by size category, was calculated as:

$$SE(B) = \left[\sum_{j=1}^{3} \left[\left(\left(\frac{SE(D)_j}{\overline{D}_j} \right)^2 + \left(\frac{SE(W)_j}{\overline{W}_j} \right)^2 \right)^{\frac{1}{2}} (B_j) \right]^2 \right]^{\frac{1}{2}}, \tag{4}$$

with symbols as previously defined, and assuming that the area (A) (used within the calculation for B_j) is known without error. A further assumption is that the errors in mean density and mean weight, and among size classes, are independent and random.

Note that EXCEL spreadsheets are used for many of these calculations, and that each result from a sequence of calculations is not rounded off. Therefore, any differences between calculations and values shown in the tables are due to rounding errors.

Green urchin densities increased over the years of the surveys, until it became difficult to measure all urchins within the time and budget constraints, and it became necessary to change the methodology. On some transect lines, (i.e., the Stephenson Islets, because it has the highest number of transects), instead of measuring all green urchins in every quadrat, they were measured in every second quadrat and urchins in the alternate quadrats were counted only. These unmeasured urchins (or "unknowns") were incorporated into the data analyses. The estimates of legal and sublegal urchins within the unmeasured urchins were calculated using the proportions of measured legal-sized and sublegal-sized urchins of all the measured urchins. These values were then added to the number of measured legal-sized and sublegal-sized urchins to calculate the total numbers of each of these size classes. These adjustments of the data to include unmeasured urchins in the data analyses were done for many of the tables, including density by transect and site, density by depth range, and the biomass estimates.

RESULTS

(a) OCTOBER 26-27, 2006 SURVEY

Nine transect lines were surveyed in the Stephenson Islets (Table 1, Fig. 1b; missing Transect 7 this survey), two transects were surveyed at Stubbs Island (Fig. 1c; missing Transect 15 and 17), and four transects in the Plumper Islands (Fig. 1c) during this survey. Some transects were missed due to very strong winds and rough seas. In addition, for the first time in 11 years of surveys, a population of Stellar sea lions (*Eumetopias jubatus*; approximately 50 animals or more) moved onto Stubbs Island, right over two of the transect lines, which interfered with surveying at that location.

Size: There were 546 quadrats in total that were surveyed in this survey, of which 323 quadrats were measured (Table 1). Test diameter (TD's) measurements were taken for 2,414 urchins and another 1,822 urchins were counted. The data for the unmeasured urchins were distributed between the three size classes, as described in the Data Analyses section. This adjustment revealed that of the total 4,236 green urchins observed in this survey, 1,331 (31.4%) were of legal size, 2,826 (66.7%) were sublegal-mature, and 79 (1.9%) were sublegal-immature (Table 1). Figure 2a shows the size frequency distribution for all the sites combined during the October, 2006 survey. When combining all the test diameters measured at all sites during the survey, a single distinct mode best fit the distribution ($X^2 = 90.9$; $df = 43$; $p < 0.0001$), with a mean test diameter of 49 mm (Table 2). Mean TD's and weights for urchins from all sites combined were 61.6 ± 0.2 mm and 69.5 ± 0.7 g for legal-sized urchins, 43.7 ± 0.2 mm and 27.5 ± 0.3 g for sublegal-mature urchins, and 19.5 ± 0.6 mm and 2.9 ± 0.2 g for sublegal-immature urchins (Table 3).

Density: The mean overall total density during this survey (all sites combined) was 7.76 ± 1.11 urchins/m^2 (Table 4). After adjusting for unmeasured urchins, the mean overall densities were 2.44 ± 0.49 urchins/m^2 for legal-sized urchins, 5.18 ± 0.87 urchins/m^2 for sublegal-mature urchins, and 0.15 ± 0.05 urchins/m^2 for sublegal-immature urchins.

Depth: The sample mean densities of green sea urchins by depth range for all sites combined are shown in Table 5a and Fig. 3a. The data for unmeasured urchins were proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns. The highest mean total density of green urchins for all sites combined (22.62 ± 3.55 urchins/m^2) was observed in the 1.2 to 0.0 m (4 to 0 ft) above CD range. This depth range also contained the highest densities of legal-sized (9.06 urchins/m^2) and sublegal-sized urchins (13.55 urchins/m^2) green sea urchins. As observed in past surveys, the mean total densities generally decreased continuously with each deeper depth interval. The lowest total density (1.00 ± 0.77 urchins/ m^2) of green sea urchins occurred in the deepest depth range (12.5 to 13.4 m or 41 to 44 ft below CD).

Substrate: Fig. 4a shows the mean densities of green sea urchins by substrate type for all sites combined. Smooth bedrock was the most sampled substrate (184 quadrats, with a total density of 7.76 urchins/m^2; Table 6a), followed by creviced bedrock (171 quadrats, with a total density of 9.83 urchins/m^2). The highest legal-sized (36.00 urchins/m^2), sublegal-sized (53.00 urchins/m^2) and total densities (89.00 urchins/m^2) all occurred on one single quadrat with a substrate combination of creviced bedrock, gravel and shell. There were several combinations of substrate types where no green urchins were present at all (0.00 urchins/m^2). When examining the data grouped for the primary substrate type, the highest mean overall total density of green sea urchins was observed on creviced bedrock (9.13 ± 0.77 urchins/m^2; 242 quadrats; Table 6a).

(i) Stephenson Islets

Size: There were 200 quadrats in which green urchins were measured (1,743 green urchins) and 183 quadrats in which green urchins were only counted (1,685 green urchins), for a total of 383 quadrats surveyed (total 3,428 green urchins) at the Stephenson Islets (Table 1). After adjusting for unmeasured urchins, there were 983 (28.7%) legal-sized, 2,372 (69.2%) sublegal-mature-sized, and 73 (2.1%) sublegal-immature-sized urchins. The size frequency distribution for the October, 2006 survey is shown in Fig. 2b, and the test diameter frequency analysis is presented in Table 2. Stephenson Islets showed the best fit ($X^2 = 97.6$; df = 43; $p < 0.0001$) with one dominant size mode at 48 mm TD. Mean TD's and weights for urchins from Stephenson Islets were 61.0 ± 0.2 mm and 69.9 ± 0.8 g for legal-sized urchins, 43.6 ± 0.2 mm and 28.5 ± 0.3 g for sublegal-mature urchins, and 19.5 ± 0.7 mm and 3.2 ± 0.2 g for sublegal-immature urchins (Table 3).

Density: After adjusting for the unmeasured urchins, the mean total, legal, sublegal-mature and sublegal-immature densities at the Stephenson Islets were 8.95 ±

1.37 urchins/m^2, 2.57 ± 0.67 urchins/m^2, 6.19 ± 1.04 urchins/m^2, and 0.19 ± 0.06 urchins/m^2, respectively (Table 4). The highest total (15.98 urchins/m^2) and sublegal-mature (12.06 urchins/m^2) densities occurred at Transect 11 (Table 4), while the highest densities of legal-sized (5.88 urchins/m^2) and sublegal-immature-sized (0.38 urchins/m^2) green urchins were observed at Transect 6.

Depth: The highest mean total (28.03 ± 4.46 urchins/m^2), legal-sized (11.68 urchins/m^2), and sublegal-sized (16.35 urchins/m^2) densities all occurred in the 1.2 to 0.0 m (4.0 to 0.0 ft) above CD depth range (34 quadrats; Table 5b; Fig. 3b). The densities below this depth range generally decreased with each depth increment.

Substrate: The most frequently surveyed substrate was smooth bedrock (152 quadrats, with a total density of 8.07 urchins/m^2; Table 6b and Fig. 4b), followed by creviced bedrock (129 quadrats, with a total density of 11.65 urchins/m^2). Like the results presented for all of the sites combined, the highest legal-sized (36.00 urchins/m^2), sublegal-sized (53.00 urchins/m^2) and total densities (89.00 urchins/m^2) all occurred on one single quadrat with a substrate combination of creviced bedrock, gravel and shell. Creviced bedrock was the primary substrate with the highest mean overall total density (11.12 ± 1.02 urchins/m^2; 169 quadrats; Table 6b).

(ii) Stubbs Island

Size: Unfortunately only 2 of the 4 transects at Stubbs Island were surveyed during this survey, due to interference by a population of Stellar sea lions. However, green sea urchins were measured in 32 of the 33 quadrats surveyed at Stubbs Island, totalling 263 measurements (Table 1). After adjusting for unmeasured urchins, there were 125 (47.5%) legal-sized, 135 (51.3%) sublegal-mature, and 3 (1.1%) sublegal-immature urchins. The analysis of the size frequency distribution (Table 2 and Fig. 2c) showed that there was one main frequency mode at 53 mm (X^2 = 76.1; df = 35; p = 0.0001). Mean TD's and weights of urchins at Stubbs Island in October, 2006 were: 65.4 ± 0.7 mm and 82.5 ± 2.5 g for legal-sized urchins; 44.3 ± 0.5 mm and 28.6 ± 0.8 g for sublegal-mature urchins; and 19.0 ± 2.1 mm and 2.8 ± 0.8 g for sublegal-immature urchins (Table 3).

Density: The mean overall total, legal, sublegal-mature and sublegal-immature densities at Stubbs Island were 7.97 ± 5.91 urchins/m^2, 3.79 ± 2.79 urchins/m^2, 4.09 ± 3.17 urchins/m^2, and 0.09 ± 0.04 urchins/m^2, respectively (Table 4). Only two transects were surveyed this time: Transects 16 and 18. As in the past, the densities for all (total), legal-sized, and sublegal-mature-sized urchins at Transect 16 (13.11, 6.21, 6.84) urchins/m^2, respectively), were all higher than at Transect 18. However, the sublegal-immature densities were highest at Transect 18 (0.14 urchins/m^2) during this survey.

Depth: The highest mean total (14.00 ± 6.13 urchins/m^2), legal (6.80 urchins/m^2), and sublegal (7.20 urchins/m^2) densities all occurred in the 1.8 to 3.0 m (6 to 10 ft) below CD depth range (Table 5c; Fig. 3c). In general, the densities declined with deeper depths.

Substrate: The substrate most frequently surveyed at Stubbs Island was smooth bedrock (22 quadrats, with a total density of 6.91 urchins/m^2; Table 6c). The highest mean total (24.67 urchins/m^2), legal (11.67 urchins/m^2), and sublegal (13.00 urchins/m^2) densities occurred on a substrate of creviced bedrock with boulders and cobble (three quadrats; Table 6c and Fig. 4c). The primary (main) substrate with the highest mean overall total density (10.09 ± 3.15 urchins/m^2) was creviced bedrock.

(iii) Plumper Islands

Size: During the survey there were 130 quadrats surveyed in total at the Plumper Islands, of which urchins were measured in 91 quadrats (Table 1). There were 416 green urchins measured and another 129 that were only counted, for a total of 545. After adjusting for unmeasured urchins, there were 223 (40.9%) legal-sized urchins, 319 (58.5%) sublegal-mature urchins, and 3 (0.6%) sublegal-immature urchins (Table 1). The size frequency distribution for the Plumper Islands is presented in Fig. 2d, and Table 2 presents the results of the test diameter frequency analysis. Like the other two survey locations, the best fit for the model was one single frequency mode, located at 50 mm (X^2 = 58.0; df = 33; p = 0.0045). The mean TD's and weights for legal, sublegal-mature and immature-sized urchins were 61.6 ± 0.5 mm and 65.9 ± 1.6 g, 44.3 ± 0.5 mm and 26.5 ± 0.7 g, and 20.0 ± 0.6 mm and 2.5 ± 0.2 g, respectively (Table 3).

Density: The mean densities at the Plumper Islands in October, 2006 (after adjusting for unmeasured urchins) were 4.19 ± 1.15 urchins/m^2 for all size categories combined (total), 1.72 ± 0.44 urchins/m^2 for legal-sized urchins, 2.45 ± 0.78 urchins/m^2 for sublegal-mature urchins, and 0.02 ± 0.03 urchins/m^2 for sublegal-immature urchins (Table 4). The highest mean total (6.78 urchins/m^2) and sublegal-mature (4.39 urchins/m^2) densities occurred at Transect 22. The highest mean legal-sized green urchin densities (2.42 urchins/m^2) occurred at Transect 21, and the only sublegal-mature-sized urchins occurred at Transect 23 (0.14 urchins/m^2).

Depth: The highest mean total (7.89 ± 2.90 urchins/m^2) and sublegal-sized (5.67 urchins/m^2) green urchin densities occurred at a depth interval of 0.9 to 0.0 m (3 to 0 ft) above CD (Table 5d; Fig. 3d). The highest legal-sized density (3.63 urchins/m^2) occurred at a depth interval of 6.4 to 7.6 m (21 to 25 ft) below CD. There was not the gradual decrease in total density with each increment of depth at this site as observed in most other surveys and sites, but rather an alternating decrease/increase with each depth range (Table 5d).

Substrate: The most frequently observed substrate in the Plumper Islands was creviced bedrock (38 quadrats, with a total mean density of 4.29 urchins/m^2; Table 6d; Fig. 4d). The highest mean total density (12.00 urchins/m^2) and the highest mean legal density (7.00 urchins/m^2) occurred on a substrate of cobble and creviced bedrock, whereas the substrate with the highest mean sublegal density (6.00 urchins/m^2) was cobble with shell. The main substrate with the highest mean overall total density (7.07 ± 1.47 urchins/m^2) was also cobble.

(iv) Dissection Data

Lab measurements were performed using the same method initiated in October, 2002 (Waddell and Perry 2005), which is slightly different than in previous surveys. There were 128 green sea urchins that were randomly collected from all depths and all locations and fully measured and analyzed in the same method as in all the other surveys (Table 7). In addition, there were an extra 153 urchins (in total) that were collected from all of the sites that only had their test heights, test diameters and total wet weights measured. Therefore there are two sample sizes presented in Table 7. These additional measurements were taken in order to calculate a more accurate test diameter/wet weight relationship (i.e. providing a larger sample size, without spending an inordinate amount of time with all of the other measurements and dissections, and without killing the animals).

The legal-sized and sublegal-mature-sized green urchins randomly selected from Stubbs Island had the largest mean measurements for all of the lab measurements taken in October, 2006 (Table 7). However, roe quality for these urchins was poor (discussed later). The legal-sized urchins randomly selected from the Stephenson Islets had the smallest mean measurements for all lab measurements taken, except for the mean test height, which was the second largest. Sublegal-sized urchins randomly selected from the Plumper Islands had the smallest mean measurements for all lab measurements taken, except for the mean stomach and contents weight, which was second largest (Table 7). These results agreed with the field survey data (which had a larger sample size than the lab data), where the mean legal-sized and sublegal-mature-sized test diameters and mean weights were highest at Stubbs Island, the mean legal-sized test diameters were smallest at the Stephenson Islets, and the mean sublegal-mature weights were smallest in the Plumper Islands (Table 3). However, the field survey data showed that at the Plumper Islands, legal-sized urchins had the smallest mean weight and sublegal-mature urchins had a mean test diameter that was the same as for urchins from Stubbs Island.

A test for homogeneity of regression slopes showed there was a significant difference between the slopes of the regression lines for the relationship between test diameter and the natural log transformation (to approximate normality) of the total wet weight for the three separate sites (F value = 7.07 with df = 278 and $p < 0.05$). Therefore individual allometric equations ($W=\alpha TD^{\beta}$) were used for each site in the October, 2006 survey when calculating the total wet weight (in grams) from the TD (in millimeters).

The best (i.e., highest R^2) power relationships were calculated between TD (in millimeters) and test heights (in millimeters; Figs. 5 and 6), TD (in millimeters) and total wet weight (in grams; Figs. 7 and 8), and TD (in millimeters) and gonad weight (in grams; Figs. 9 and 10), for all sites combined and for each of the three sites separately, using EXCEL (see figures for equations).

Roe quality is determined by both colour and texture, the best quality having an orange/yellow colour and a firm texture. During the October, 2006 survey, legal-sized urchins with the highest percentage (33.3%) of the best quality roe occurred at the Plumper Islands, followed by urchins from the Stephenson Islets (32.4%: Table 8).

Legal-sized and sublegal-sized green urchins randomly collected from Stubbs Island had the poorest roe quality of all the sites. In fact, none of the urchins sampled from Stubbs Island were of the highest quality (however the sample size was very low (n=5 for legal-sized urchins and n=4 for sublegal-sized urchins)). In contrast, the mean roe recovery rate (total gonad weight (all grades) divided by the total drained weight of all urchins sampled) was highest for legal-sized (20.3%) and sublegal-sized (16.3%) urchins from Stubbs Island, lowest for legal-sized (13.8%) urchins from the Stephenson Islets, and lowest for sublegal-sized (11.9%) urchins from the Plumper Islands (Table 8).

(v) Biomass Estimates

The mean total density at the Stephenson Islets in October, 2006 (8.95 urchins/m^2; Table 4) was extrapolated over the total area between zero and 10 m below CD (485,200 m^2), to derive that there were 4,342,730 ± 665,998 green sea urchins of all sizes at this site (Table 9). This included 1,245,304 ± 323,017 legal-sized, 3,004,946 ± 507,018 sublegal-mature, and 93,746 ± 26,752 immature green urchins. Since a test for homogeneity showed there was a significant difference between the slopes of the TD-total wet weight regressions for the three sites, the TD-total wet weight relationship from the dissection data for all urchins collected only from the Stephenson Islets in October, 2006 (Fig. 8a) was applied to all the test measurements recorded in the field for the Stephenson Islets. Mean individual wet weights were then calculated for the three size classes. The mean weights per legal-sized, sublegal-mature-sized and immature-sized green sea urchin from Stephenson Islets were determined to be 69.9 ± 0.8 g, 28.5 ± 0.3 g, and 3.2 ± 0.2 g, respectively (Table 3). Multiplying the individual weights with the abundances gave total biomasses of 87.00 ± 22.58 t, 85.71 ± 14.47 t, and 0.30 ± 0.09 t for legal-sized, sublegal-mature and sublegal-immature green sea urchins at Stephenson Islets in October, 2006 (Table 9). The overall total biomass was 173.01 ± 26.82 t.

By extrapolating the mean densities (Table 4) over the total area at Stubbs Island, it was determined that there were 156,206 ± 115,908 green urchins in total, of which 74,242 ± 54,678 were of legal size, 80,182 ± 62,094 that were sublegal-mature, and 1,782 ± 864 that were immature (Table 9). The mean individual wet weights, calculated using the TD-total wet weight relationship for Stubbs Island urchins only (Fig. 8b), were 82.5 ± 2.5 g, 28.6 ± 0.8 g, and 2.8 ± 0.8 g for legal-sized, sublegal-mature-sized, and sublegal-immature green urchins, respectively (Table 3). The total biomass at Stubbs Island in October, 2006 was 8.42 ± 4.85 t (Table 9). This was comprised of 6.12 ± 4.52 t of legal-sized urchins, 2.30 ± 1.78 t of sublegal-mature urchins, and 0.005 ± 0.003 t of sublegal-immature urchins.

The estimated numbers of green urchins in the Plumper Islands survey site in October, 2006, based on the calculated mean densities (Table 4), were 383,560 ± 85,996 legal-sized urchins, 548,680 ± 174,788 sublegal-mature urchins, and 5,160 ± 5,780 sublegal-immature urchins, for a total of 937,400 ± 179,695 green urchins (Table 9). The mean individual wet weights were calculated using the TD-total wet weight relationship for Plumper Island urchins only (Fig. 8c). They were 65.9 ± 1.6 g, 26.5 ± 0.7 g, and 2.5 ± 0.2 g for legal-sized, sublegal-mature, and sublegal-immature urchins, respectively (Table 3). The biomass estimates were 25.29 ± 5.69 t of legal-sized urchins, 14.55 ± 4.64 t of

sublegal-mature urchins, and 0.013 ± 0.014 t of immature urchins, for a total biomass estimate of 39.85 ± 7.34 t (Table 9).

(b) THE FISHERY

The British Columbia green sea urchin fishery started in 1987, and has had many management restrictions placed on it as it has developed over the years. Restrictions in the number of licenses and of harvesting techniques (hand-picking by divers only), a minimum size limit of 55 mm, Management Area closures, area quotas, Individual Quotas (IQ's), and fishing seasons are all controls that managers have put in place to regulate this fishery. The areas open to commercial fishing during the 2005/2006 season included Areas 11, 12, 13A, 13B, 18, 19, and 20 in the South Coast. During the 2006/2007 season, only Areas 12, 13A, 13B, 18 and 19 were open to commercial fishing. The quota allowed for Area 12 (where the study area is located) was 224,869 lbs (102.00 t) in 2005/2006 and 252,974 lbs (114.75 t) in 2006/2007.

Starting in the 2001/2002 fishing season, the international market began to change, causing a large impact on the B.C. green urchin fishery. There has been an oversupply of green sea urchins on the Japanese market, primarily supplied from Russia, which has caused the global price of green urchins to drop dramatically. The Japanese buyers have not been as interested in buying green urchins from B.C. because they have been able to get an ample supply from Russia for a lower price. The B.C. processors have only been able to sell to Japan when the weather was too rough for the Russian packers to travel (D & D Pacific Fisheries Ltd. 2002). As a result, only 68% of the fishery's total allowable catch (TAC) was harvested in the 2001/2002 fishing season, 80% in 2002/2003, 90% in 2003/2004, 44% in the 2004/2005, 20.5% in 2005/2006, and only 10.8 % in the 2006/2007 fishing season (D & D Pacific Fisheries Ltd. 2002, 2003, 2004, 2005, 2006, and 2007).

(c) FISHING EXPLOITATION

The exploitation of green sea urchins from the Stephenson Islets during the fishing season has been calculated for every survey in the past. However, no fishing occurred for green urchins in the Stephenson Islets in either the 2005/06 or 2006/07 commercial fishing seasons, due to current market conditions in Japan (i.e. oversupply of urchins from Russia, and current low demand and low market price for British Columbia sea urchins). Therefore the fishing exploitation was 0.0 for these two seasons.

DISCUSSION

There was no survey performed in the fall previous (2005) to this survey due to budget constraints. Therefore, this survey (October, 2006) will be compared to the survey conducted in November, 2004 (Waddell and Perry 2006).

(a) SIZE DISTRIBUTION CHANGES

The percentage of legal-sized urchins increased from November, 2004 to October, 2006, at all three sites, especially at the Plumper Islands. The percentage of sublegal-mature green urchins at the Stephenson Islets and Stubbs Islands increased from

November, 2004 to October, 2006, but decreased at the Plumper Islands. The percentages of immature green urchins decreased between November, 2004 and October, 2006 at all three sites, especially at the Plumper Islands. The percentages of immature urchins in November, 2004 were the highest of all surveys since 1996 at all three sites, and were thought to be the result of a very successful spawning event and settlement in the spring of 2004 (Waddell and Perry 2006). This information suggests that recruitment was likely poor from spawning in the spring of 2005 or 2006, resulting in a decrease in the percentage of immature urchins. Growth of the older urchins, and no harvesting at the Stephenson Islets in 2005/2006 increased the percentages of the larger size classes. In addition, the large increase of legal-sized urchins at the Plumper Islands is probably due to the fact that only one transect was surveyed at that site in November, 2004, but 4 transects were surveyed in October, 2006, providing a better indication of true size.

When comparing among sites, the percentage of legal-sized urchins was highest at Stubbs Island in October, 2006, followed by the Plumper Islands, and lowest at the Stephenson Islets. The percentage of legal-sized urchins is expected to be lowest at the Stephenson Islets because urchins are harvested there annually (except for the past season) but not harvested at the other two locations.

The size frequency distributions have been different for each of the three sites in each of the different surveys. Since test size is not a reliable index of age, these changes are difficult to analyze and interpret. Green sea urchins have discontinuous growth, which fluctuates with the availability and species of vegetation (Himmelman *et al.* 1983, Larson *et al.* 1980, Vadas 1977, Vadas *et al.* 2002). As in past surveys, we used the computer program "MIX3aa" to analyze the size distribution data of urchins measured in the October, 2006 survey. Again, we found it difficult to properly determine the distribution of age classes, for reasons mentioned above (i.e., discontinuous growth in urchins). This model fit best for one frequency mode for all three sites and for all size frequency data combined in October, 2006, but we expect there is more than one age/size class at each of these locations. We expect there are many age classes with wide variation and overlaps in test diameter, so that individual modes blend together to create the appearance of a single mode. It is impossible to tease out information to determine the different age classes, especially without a fully developed ageing technique or an accepted maximum age for British Columbia green sea urchins at this time. A growth study has recently been undertaken at the Pacific Biological Station laboratory, using the growth rings found in cross-sections of the rotules of the Aristotle's Lantern (mouth parts), with the goal of developing a reliable ageing technique. This technique is being validated by studying the growth rings in green urchins of known age to compare with field samples. The hope is that this information will assist in interpreting age frequency distributions in the future.

It appears that the size frequency distributions have shifted towards larger TD's for each of the three survey sites between the November, 2004 and October, 2006 surveys. At the Stephenson Islets in November, 2004, there were two frequency modes, at 32 and 52 mm, but by October, 2006, there was only a single mode at 48 mm. There were successful spawns in the springs of 2003 and 2004 (Waddell and Perry 2006) but

little evidence there has been another one since then. The high frequency of immature-sized urchins in November, 2004 all but disappeared by October, 2006, while the frequency of larger urchins has increased. There has also been less commercial fishing for the last 2 years, so fewer of the larger urchins have been removed from the population. At Stubbs Island in November, 2004, there was a wide distribution of urchins, with three frequency modes at 27, 44 and 63 mm. In October, 2006 at this location, there was little evidence of smaller-sized urchins, and only one mode, at 53 mm. In November, 2004, the urchins at the Plumper Islands had a single size frequency mode, with a mean of 30 mm. At the same location in October, 2006, there was still only one size frequency mode, but it shifted to a significantly larger mean of 50 mm. This new mode likely represents the smaller mode in November, 2004 after two years of growth. Like the other two sites, there were very few newly recruited juvenile urchins.

(b) LENGTH-WEIGHT RELATIONSHIPS

When comparing between sites, the largest mean legal-sized TD for green urchins measured in the field in the October, 2006 survey was observed at Stubbs Island, followed by the Plumper Islands, and was smallest for the Stephenson Islets. Legal-sized green urchins at Stubbs Island also had the highest mean total wet weight of the three sites, whereas urchins from the Plumper Islands had the lowest. One would expect that urchins from the Stephenson Islets would be smaller in size in comparison to the other sites, as this location has been open to fishing since the commercial green urchin fishery started in 1988. The majority of the larger urchins likely would have been removed from this site over time by the fishery, thus lowering the mean overall size. Conversely, one would also expect that urchins at the other two sites, Stubbs Island and the Plumper Islands, would be larger in size as these sites have been closed to commercial fishing for scientific research purposes since 1995. The unfished populations would have been left to continue growing (except for small amounts of "accidental harvesting"; Waddell *et al.* 2003), resulting in a higher abundance of larger urchins, assuming there was low natural mortality and emigration. Prior to 1995, the Plumper Islands were open to fishing, whereas Stubbs Island was considered locally as a "reserve", so one would expect that the largest green sea urchins should be observed at Stubbs Island. These expected trends have generally been observed in the surveys conducted since 1996 (see Waddell *et al.* (1997, 2002, 2003) and Waddell and Perry (2005) for data prior to 2003). In November, 2004, the mean TD's and weights at the Stephenson Islets were the lowest for this site over all the surveys (Waddell and Perry 2006). However, in October, 2006, the mean TD was the second largest at this site for all of the surveys, while the mean total wet weight was the second lowest at this site, over all of the surveys. At Stubbs Island, the mean TD and total wet weight deceased slightly between November, 2004 and October, 2006.

The mean sublegal-mature TD's and weights increased at all three sites between November, 2004 and October, 2006.

(c) DENSITY

(i) General Changes

The mean density of legal-sized green urchins increased at all three sites between November, 2004 and October, 2006, particularly at the Plumper Islands (likely due to the

same reason mentioned earlier – there was only one transect surveyed at the Plumper Islands in November, 2004, which likely produced a lower than normal density for that survey). The densities of sublegal-mature green urchins decreased between November, 2004 and October, 2006 at the Stephenson Islets and the Plumper Islands, but increased very slightly at Stubbs Island. The mean densities of immature urchins in November, 2004 were particularly high, and were the highest for all surveys since 1995, indicating there was a very successful spawn and recruitment of juvenile green urchins in the spring of 2004. In contrast, the mean densities of immature urchins decreased significantly (by ten fold or more) at all sites between November, 2004 and October, 2006, but this is not surprising after a year with a significantly high density.

The mean overall total density (all size classes and sites combined) decreased from November, 2004 to October, 2006. In addition, the mean total densities (all size classes combined) decreased between November, 2004 (Waddell and Perry 2006) and October, 2006 at all three sites of the survey area, especially at the Plumper Islands. However, the total densities at the Stephenson Islets and Stubbs Island in October 2006 were still higher than the total densities in October, 2003. The decreases in total densities were mainly due to decreases in the densities of sublegal-immature-sized urchins.

When comparing among the three sites, the highest mean densities of legal-sized urchins occurred at Stubbs Island in the October, 2006 survey, as observed in many, previous surveys. This would be expected as the urchins have not been commercially harvested here, and also they have historically been the largest urchins, and remain the largest. It would be expected that the lowest density of legal-sized urchins would occur at the Stephenson Islets since they have been harvested there since approximately 1988 but instead, the lowest density of legal-sized urchins in October, 2006 occurred at the Plumper Islands. The mean densities of both sublegal-mature and sublegal-immature urchins were highest at the Stephenson Islets and lowest at the Plumper Islands during the October, 2006 survey.

(ii) Changes with Depth

In general, green sea urchins in this study area have occurred at greater densities in shallower waters during past surveys, and have decreased in density with increasing depth. Himmelman (1986) also observed green urchin abundances generally decreased at greater depths. However, there were subtle differences in depth distributions between the sites and size classes in our surveys. While no urchins were observed shallower than 1.2 m above CD on this survey at any site, the next deeper depth category had the highest mean densities of green urchins for all size categories at the Stephenson Islets (0.0 to 1.2 m above CD) and the highest mean densities of sublegal and "total" (all size categories combined) urchins at the Plumper Islands (0.0 to 0.9 m above CD). The highest densities for all size categories of urchins at Stubbs Island occurred slightly deeper at 1.8 to 3.0 m below CD, and the highest density of legal-sized urchins at the Plumper Islands occurred at a depth category of 6.4 to 7.6 m below CD. Although these depth distributions are not exactly the same as observed in November, 2004, they are similar to distributions seen in previous surveys. It is unknown why urchins in the Plumper Islands occur in higher densities at deeper depth intervals in some years (just legal-sized urchins in the October,

2006 survey), but possibly urchins at this site depend more upon drift algae than attached algae and must go deeper to find it.

(iii) Changes with Substrate

The type of substrate where the highest densities of urchins occur seems to vary with survey, site, and size class. During the October, 2006 survey, the highest total mean density by main substrate occurred on creviced bedrock at the Stephenson Islets and Stubbs Island, and occurred on cobble at the Plumper Islands. All size classes were in highest density on creviced bedrock with gravel and shell at the Stephenson Islets, and on creviced bedrock with boulders and cobble at Stubbs Island. At the Plumper Islands, densities were highest for legal-sized and "total" (all sizes combined) urchins on cobble with creviced bedrock, and highest for sublegal-sized urchins on cobble with shell. Part of these differences in substrate preferences may be due to the fact that different divers were involved in the surveys, and they may have used different criteria for determining between the substrate types, especially between the smooth and creviced bedrock. Also, there were two dive teams for each survey, so again the dive teams may have used different criteria, even though the teams are given guidelines for determining between the substrates. Additionally, as mentioned previously, the transect lines are never repeated exactly for each surveys. Regardless, the general trend over all the surveys (since 1995), not surprisingly, was that green sea urchins were observed in this survey area more consistently and in higher densities on smooth and creviced bedrock, boulders, cobble and shell, less frequently on gravel or pea gravel, and almost never on sand.

(d) DISSECTION RESULTS

The mean stomach weights for legal-sized and sublegal-mature urchins from all three sites in October, 2006 were average when compared to past surveys (Waddell and Perry 2005, 2006). The mean gonad weights for legal-sized urchins in October, 2006 were lowest among all surveys at both Stephenson Islets and the Plumper Islands, but were average for legal-sized urchins from Stubbs Island and for sublegal-mature urchins from all sites.

The quality of roe varies widely each year at the survey sites. Legal-sized green urchins from the Plumper Islands had the highest percentage of the best quality roe (good colour and texture) of all three sites in October, 2006, while legal-sized urchins from Stubbs Island were the lowest, as in the last two previous surveys (Waddell and Perry 2006). There were no legal-sized or sublegal-sized urchins at Stubbs Island with the highest quality roe at all, but the sample size was extremely low. Despite this, the highest mean roe recovery rates (the percentage of total gonad weights (regardless of quality) divided by the total drained weight of all urchins collected) were observed for legal and sublegal-sized urchins at Stubbs Island in October, 2006. Legal-sized urchins at the Stephenson Islets and sublegal-sized urchins at the Plumper Islands had the lowest mean roe recovery rates in this survey.

(e) CHANGES IN BIOMASS

The criterion we used to estimate the "total area" of green sea urchin habitat for the biomass calculations was "all area with a depth between 0 and 10 m below CD". The

majority of green urchins are found within this depth range, however, it is realized that they have a wide range in habitable depth, so these are conservative estimates. The area estimates are largest (485,200 m^2) for the Stephenson Islets, so it is not surprising that the biomass estimates are highest for that location. The area estimate for the Plumper Islands (223,600 m^2) is about half the size as for the Stephenson Islets, and the biomass estimates are always smaller. Stubbs Island has the smallest area estimate (19,600 m^2, only 4% of the area of the Stephenson Islets), and always has a much smaller biomass estimate than the other two sites.

During the first three years of surveys both pre- and post-fishery surveys were conducted, meaning that changes in the total legal-sized biomass could be calculated between the start and finish of a fishing season at the Stephenson Islets (Waddell *et al.* 1997, 2002, 2003). Post-season surveys were subsequently eliminated due to funding restraints. However, changes in biomass between years can still be calculated. The estimate of total biomass of legal-sized green urchins at the Stephenson Islets site increased from 61.11 ± 8.29 t in November, 2004 (Waddell and Perry 2006) to 87.00 ± 22.58 t in October, 2006 after 7.25 t were removed during the 2004/2005 fishing season. There were no green sea urchins commercially harvested from the Stephenson Islets during the 2005/06 fishing season. The legal biomass therefore actually increased by (87.00 + 7.25 – 61.11 =) 33.14 t over the two year period from November, 2004 to October, 2006, equivalent to a 54% increase.

At Stephenson Islets, the biomass estimate of sublegal-mature green urchins increased from 71.79 ± 17.41 t in November, 2004 (Waddell and Perry 2006) to 85.71 ± 14.47 t in October, 2006, an increase of 13.92 t or 19% over two years. The biomass estimate of immature urchins at Stephenson Islets decreased drastically from a high of 1.87 ± 0.37 t in November, 2004 (the largest biomass estimate of immature urchins for the Stephenson Islets since 1996; Waddell and Perry 2006) to 0.30 ± 0.09 t in October, 2006. This is a decrease of 1.57 t or 84%.

The overall total (all sizes combined) biomass estimate for the Stephenson Islets increased from 134.77 ± 19.29 t in November, 2004 (Waddell and Perry 2006) to 173.01 ± 26.82 t in October, 2006. We have not taken into account the biomass of legal-sized urchins removed by the fishery each year, and this will be discussed further in another paper.

The biomass estimate of legal-sized urchins at Stubbs Island decreased very slightly from 6.21 ± 1.70 t in November, 2004 (Waddell and Perry 2006) to 6.12 ± 4.52 t in October, 2006. The biomass estimates of sublegal-mature urchins at Stubbs Island increased from 1.76 ± 0.81 t in November, 2004 to 2.30 ± 1.78 t in October, 2006, whereas the biomass estimate of immature urchins decreased by 92% (from 0.06 ± 0.03 t in November, 2004 (Waddell and Perry 2006) to 0.005 ± 0.003 t in October, 2006) over the same time period.

The biomass estimate of legal-sized urchins in the Plumper Islands increased substantially (by 20.64 t or 444%), from 4.65 t in November, 2004 (Waddell and Perry

2006) to 25.29 ± 5.69 t in October, 2006. (Note that the value in November, 2004 was not a good estimate as only one transect was completed in that survey). In contrast, the biomass estimate of sublegal-mature urchins decreased from 24.58 t in November, 2004 (Waddell and Perry 2006) to 14.55 ± 4.64 t in October, 2006. The biomass estimate of immature urchins decreased significantly from its highest value of all the surveys (1.86 t) in November, 2004 (Waddell and Perry 2006) to its lowest value of all the surveys (0.013 ± 0.014 t) in October, 2006.

(f) SAMPLING PROBLEMS

Sampling problems can potentially cause differences between survey results. For instance, it was noted that occasionally the divers started surveying transects deeper than 10.0 m below CD or surveyed shallower than 0 m CD. Since the area estimate for the Stephenson Islets was based on the 10 m isobath, and green urchins are usually sparse at depths below this, the divers' data were truncated to 0 to 10 m (33 ft) below CD to calculate the density so that the sampling occurred within the area estimate (however, the original data were used for the size frequency analyses). Second, the divers occasionally neglected to note empty quadrats. This was evident when the recorded depths between the one meter quadrats had a difference of more than 4 ft. "Empty quadrats" were approximately added in, thus reducing the overestimate of density and biomass. Thirdly, due to various reasons (poor weather conditions, strong tidal currents, divers running out of air or having other difficulties, etc.), the divers did not always survey the full length of some of the transects. Since the divers always started at the deep end of the transect and worked their way to the shallow end, the shallower depths were sometimes not sampled sufficiently. The densities by depth analyses show that densities were generally higher in the shallower depths, especially for the Stephenson Islets and Stubbs Island. Therefore, density and biomass estimates may be underestimated (not as much in later surveys as in earlier surveys). There was no method available to compensate for the lack of these data.

SUMMARY

Observations from surveys performed in October, 2003 and November, 2004 indicated that they represented contrasting years (Waddell and Perry 2006). These surveys had variables that often represented extreme values, either high or low, as compared to results observed throughout the whole data series. This indicated there had possibly been a break in the trends that had been observed since the start of the surveys in 1995 and 1996. The current survey (October, 2006) was the next one conducted since 2004. The mean legal and sublegal-mature TD's increased at all locations from the November, 2004 survey (except for legal-sized urchins at Stubbs Island). Although the mean total wet weights for legal-sized urchins at the Stephenson Islets and sublegal-sized urchins from all the locations increased since November, 2004, they still all remained relatively low when compared to the surveys overall.

The mean densities were relatively high for legal and sublegal-mature urchins at the Stephenson Islets and Stubbs Island and moderate at the Plumper Islands in October, 2006. However, the mean densities of immature urchins were among the lowest of all

surveys at all three sites. A more complete comparison over all years of survey data will be presented in a future publication.

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Table 1. Numbers (N) and percentages (P) of green sea urchins of legal size, sublegal-mature size, sublegal-immature size, unknown size (i.e., counted only), and all sizes (total) for all sites, measured during the October, 2006 survey. Note that measuring was incomplete (urchins were measured in most quadrats but only counted in the remainder) for both of these surveys. The numbers in the brackets in the lighter font indicate the actual measured values while the darker font indicates the best estimates (the "unknowns" were proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and a zero value was assigned to the unknowns). (M=measured quadrats; T=measured plus counted quadrats; Legal ≥ 55 mm test diameter (TD); Sublegal-mature = 25 mm ≤ TD < 55 mm TD; Sublegal-immature = < 25 mm; Total Number = total number of green sea urchins measured).

Site	Survey Date	No. of Quads	N or P	Number of Legal	Number of Sublegal-mature	Number of Sublegal-immature	Number of Unknown	Total Number
All Sites Combined	Oct. 2006	546 T 323 M	N P	**1,331** (778) **31.4%** (18.4%)	**2,826** (1,593) **66.7%** (37.6%)	**79** (43) **1.9%** (1.0%)	**0** (1,822) **0%** (43.0%)	**4,236**
Stephenson Islets	Oct. 2006	383 T 200 M	N P	**983** (496) **28.7%** (14.5%)	**2,372** (1,209) **69.2%** (35.3%)	**73** (38) **2.1%** (1.1%)	**0** (1,685) **0%** (49.2%)	**3,428**
Stubbs Island	Oct. 2006	33 T 32 M	N P	**125** (121) **47.5%** (46.0%)	**135** (132) **51.3%** (50.2%)	**3** (2) **1.1%** (0.8%)	**0** (8) **0%** (3.0%)	**263**
Plumper Islands	Oct. 2006	130 T 91 M	N P	**223** (161) **40.9%** (29.5%)	**319** (252) **58.5%** (46.2%)	**3** (3) **0.6%** (0.6%)	**0** (129) **0%** (23.7%)	**545**

Table 2. Green sea urchin test diameter frequency distribution analysis for the October, 2006 survey. Results were obtained using the analysis software "MIX3aa" (Macdonald 1994). (Sigma = standard deviation, X^2 = chi-square goodness of fit value, DF = degrees of freedom, P-value = the p-value of the chi-square test).

Site	Survey	Frequency Mode	Mode Mean (mm)	Sigma (mm)	Proportion Of Population	X^2	DF	P-value
All Sites Combined	Oct. 2006	1	49	11.6	1.00	90.9	43	<0.0001
Stephenson Islets	Oct. 2006	1	48	11.2	1.00	97.6	43	<0.0001
Stubbs Island	Oct. 2006	1	53	13.1	1.00	76.1	35	0.0001
Plumper Islands	Oct. 2006	1	50	11.6	1.00	58.0	33	0.0045

Table 3. Means and standard errors (SE) of test diameters (TD) (using October, 2006 field survey data) and weight (using TD-total wet weight relationships from October, 2006 lab measurements, and applying to field survey data) of legal, sublegal-mature and immature green sea urchins from each of the survey sites. (Legal ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD).

Site	Size	Sample Size	Mean TD (mm)	SE of Mean TD (mm)	Mean Weight (g)	SE of Mean Weight (g)
All Sites Combined	Legal	1000	61.6	0.2	69.5	0.7
	Sublegal-Mature	1882	43.7	0.2	27.5	0.3
	Sublegal-Immature	51	19.5	0.6	2.9	0.2
Stephenson Islets	Legal	695	61.0	0.2	69.9	0.8
	Sublegal-Mature	1452	43.6	0.2	28.5	0.3
	Sublegal-Immature	42	19.5	0.7	3.2	0.2
Stubbs Island	Legal	122	65.4	0.7	82.5	2.5
	Sublegal-Mature	138	44.3	0.5	28.6	0.8
	Sublegal-Immature	3	19.0	2.1	2.8	0.8
Plumper Islands	Legal	183	61.6	0.5	65.9	1.6
	Sublegal-Mature	292	44.3	0.5	26.5	0.7
	Sublegal-Immature	6	20.0	0.6	2.5	0.2

Table 4. Sample mean densities (urchins/m^2) by transect and overall standard errors for green sea urchins of legal size, sublegal-mature size, immature size, unknown size, and all sizes (total) in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD, Unknown = unmeasured, Total Density = density of all urchins combined. The bold numbers in the brackets indicate calculations where the unknowns have been proportioned into legal and sublegal values using the ratios from measured data, then added to the original legal and sublegal values, and assigning a zero value to the unknowns. These are considered the best estimates of the two values given. M=measured quadrats; T=total quadrats (measured and counted). Stephenson Islets = Transects 3 to 14, Stubbs Island = Transects 16 to 18, and Plumper Islands = Transects 20 to 23).

Transect Number	Number of Quadrats	Legal Density	Sublegal – Mature Density	Sublegal – Immature Density	Unknown Density	Total Density
3	30 M 58 T	2.09 **(4.31)**	3.16 **(6.52)**	0.07 **(0.14)**	5.66 **(0.00)**	10.97
5A	15 M 31 T	1.52 **(2.81)**	0.97 **(1.81)**	0.00 **(0.00)**	2.13 **(0.00)**	4.61
6	13 M 24 T	3.33 **(5.88)**	4.21 **(7.38)**	0.21 **(0.38)**	5.88 **(0.00)**	13.63
8	12 M 17 T	1.35 **(1.47)**	1.41 **(1.53)**	0.06 **(0.06)**	0.24 **(0.00)**	3.06
9	27 M 52 T	0.54 **(1.06)**	4.21 **(8.21)**	0.06 **(0.12)**	4.58 **(0.00)**	9.38
10	13 M 25 T	1.68 **(4.60)**	0.72 **(2.00)**	0.08 **(0.24)**	4.32 **(0.00)**	6.80
11	23 M 47 T	1.87 **(3.87)**	5.83 **(12.06)**	0.02 **(0.04)**	8.26 **(0.00)**	15.98
13	19 M 36 T	0.75 **(1.47)**	3.47 **(6.89)**	0.11 **(0.22)**	4.25 **(0.00)**	8.58
14	48 M 93 T	0.43 **(0.81)**	2.53 **(4.76)**	0.19 **(0.37)**	2.78 **(0.00)**	5.94
Stephenson Islets Totals or Avg.	200 M 383 T	1.30 ± 0.33 **(2.57 ± 0.67)**	3.16 ± 0.50 **(6.19 ± 1.04)**	0.10 ± 0.03 **(0.19 ± 0.06)**	4.40 ± 0.74 **(0.00)**	8.95 ± 1.37
16	19 T	6.21	6.84	0.05	0.00	13.11
18	13 M 14 T	0.21 **(0.50)**	0.14 **(0.36)**	0.07 **(0.14)**	0.57 **(0.00)**	1.00
Stubbs Island Totals or Avg.	32 M 33 T	3.67 ± 2.93 **(3.79 ± 2.79)**	4.00 ± 3.27 **(4.09 ± 3.17)**	0.06 ± 0.01 **(0.09 ± 0.04)**	0.24 ± 0.28 **(0.00)**	7.97 ± 5.91
20	18 M 42 T	0.74 **(1.48)**	0.76 **(1.55)**	0.00 **(0.00)**	1.52 **(0.00)**	3.02
21	16 M 31 T	1.42 **(2.42)**	1.55 **(2.65)**	0.00 **(0.00)**	2.10 **(0.00)**	5.06
22	36 T	2.39	4.39	0.00	0.00	6.78
23	21 T	0.00	0.67	0.14	0.00	0.81
Plumper Islands Totals or Avg.	91 M 130 T	1.24 ± 0.48 **(1.72 ± 0.44)**	1.94 ± 0.94 **(2.45 ± 0.78)**	0.02 ± 0.03 **(0.02 ± 0.03)**	0.99 ± 0.52 **(0.00)**	4.19 ± 1.15
OVERALL TOTAL	323 M 546 T	1.42 ± 0.31 **(2.44 ± 0.49)**	2.92 ± 0.45 **(5.18 ± 0.87)**	0.08 ± 0.02 **(0.15 ± 0.05)**	3.34 ± 0.62 **(0.00)**	7.76 ± 1.11

Table 5a. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below Chart Datum (CD) from all survey sites combined in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	6	0.00	0.00	0.00
-4 to 0	-1.2 to 0.0	47	9.06	13.55	22.62 ± 3.55
1 to 5	0.3 to 1.5	69	6.49	11.20	17.70 ± 1.88
6 to 10	1.8 to 3.0	99	4.45	8.19	12.65 ± 0.99
11 to 15	3.3 to 4.8	68	2.01	5.53	7.54 ± 0.84
16 to 20	4.9 to 6.1	62	1.24	2.73	3.97 ± 0.77
21 to 25	6.4 to 7.6	87	1.33	3.39	4.72 ± 0.98
26 to 30	7.9 to 9.1	115	0.71	2.59	3.30 ± 0.37
31 to 35	9.4 to 10.7	48	0.67	1.10	1.77 ± 0.36
36 to 40	11.0 to 12.2	21	0.38	0.71	1.10 ± 0.31
41 to 44	12.5 to 13.4	5	0.00	1.00	1.00 ± 0.77

Table 5b. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below Chart Datum (CD) in the Stephenson Islets in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	4	0.00	0.00	0.00
-4 to 0	-1.2 to 0.0	34	11.68	16.35	28.03 ± 4.46
1 to 5	0.3 to 1.5	48	8.31	14.77	23.08 ± 2.19
6 to 10	1.8 to 3.0	69	4.55	10.10	14.65 ± 1.17
11 to 15	3.3 to 4.8	50	1.86	6.48	8.34 ± 0.97
16 to 20	4.9 to 6.1	39	0.64	2.92	3.56 ± 0.77
21 to 25	6.4 to 7.6	67	0.79	3.76	4.55 ± 1.19
26 to 30	7.9 to 9.1	88	0.73	2.95	3.68 ± 0.45
31 to 35	9.4 to 10.7	22	0.59	1.14	1.73 ± 0.36
36 to 40	11.0 to 12.2	11	0.73	1.27	2.00 ± 0.43
41 to 44	12.5 to 13.4	1	0.00	0.00	0.00

Table 5c. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below Chart Datum (CD) at Stubbs Island in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft) below CD	Depth Range (m) below CD	Number Of Quadrats	Legal Density	Sublegal Density	Total Density
-8 to -5	-2.4 to -1.5	2	0.00	0.00	0.00
-4 to 0	-1.2 to 0.0	4	3.75	6.00	9.75 ± 7.60
1 to 5	0.3 to 1.5	6	6.33	6.50	12.83 ± 4.50
6 to 10	1.8 to 3.0	5	6.80	7.20	14.00 ± 6.13
11 to 15	3.3 to 4.8	5	4.20	4.40	8.60 ± 3.98
16 to 20	4.9 to 6.1	4	2.50	3.75	6.25 ± 2.59
21 to 25	6.4 to 7.6	4	0.25	0.50	0.75 ± 0.48
26 to 30	7.9 to 9.1	4	1.50	1.50	3.00 ± 1.78
31 to 35	9.4 to 10.7	5	0.20	0.00	0.20 ± 0.20
36 to 37	11.0 to 11.3	3	0.00	0.33	0.33 ± 0.33

Table 5d. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, and all sizes (total) by depth range (feet and meters) below Chart Datum (CD) in the Plumper Islands in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD. The unmeasured urchins have been proportioned into the legal and sublegal estimated values by using the proportions of legal and sublegal urchins in the measured data, then adding the original legal and sublegal values, and assigning a zero value to the unknowns).

Depth Range (ft) below CD	Depth Range (m) below CD	Number of Quadrats	Legal Density	Sublegal Density	Total Density
-3 to 0	-0.9 to 0.0	9	2.22	5.67	7.89 ± 2.90
1 to 5	0.3 to 1.5	15	0.47	1.93	2.40 ± 1.01
6 to 10	1.8 to 3.0	25	2.92	3.92	6.84 ± 1.39
11 to 15	3.3 to 4.8	13	1.08	3.00	4.08 ± 1.54
16 to 20	4.9 to 6.1	19	2.32	2.00	4.32 ± 1.91
21 to 25	6.4 to 7.6	16	3.63	2.81	6.44 ± 1.84
26 to 30	7.9 to 9.1	23	0.57	1.35	1.91 ± 0.47
31 to 35	9.4 to 10.7	21	0.81	1.38	2.19 ± 0.71
36 to 40	11.0 to 12.2	7	0.00	0.00	0.00
41 to 42	12.5 to 12.8	4	0.00	1.25	1.25 ± 0.95

Table 6a. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by substrate type from all survey sites combined in the October, 2006 survey. (Legal ≥ 55 mm TD, Sublegal < 55 mm TD, Unknown = unmeasured, Total Density by Main Substrate = density for all urchins within the dominant substrate type).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density	Total Density By Main Substrate
100	Bedrock (smooth)	184	1.30	3.04	3.41	7.76	
120	Bedrock (smooth)/bedrock (crevices)	1	0.00	0.00	0.00	0.00	
123	Bedrock (smooth)/bedrock (crevices)/boulders	2	0.50	2.50	0.00	3.00	
130	Bedrock (smooth)/boulders	1	0.00	0.00	14.00	14.00	
134	Bedrock (smooth)/boulders/ cobble	1	3.00	5.00	0.00	8.00	7.50 ± 0.66
135	Bedrock (smooth)/boulders/ gravel	2	1.50	2.00	0.00	3.50	
138	Bedrock (smooth)/boulders/ shell	1	0.00	0.00	0.00	0.00	
150	Bedrock (smooth)/gravel	1	2.00	4.00	0.00	6.00	
153	Bedrock (smooth)/gravel/ boulders	2	0.00	0.00	0.00	0.00	
160	Bedrock (smooth)/pea gravel	2	0.00	0.50	4.00	4.50	
200	Bedrock (crevices)	171	1.65	3.72	4.46	9.83	
230	Bedrock (crevices)/boulders	10	1.60	1.10	2.70	5.40	
234	Bedrock (crevices)/boulders/ cobble	8	5.25	8.13	1.38	14.75	
235	Bedrock (crevices)/boulders/ gravel	1	0.00	0.00	0.00	0.00	
238	Bedrock (crevices)/boulders/ shell	7	0.14	0.71	0.71	1.57	
240	Bedrock (crevices)/cobble	13	0.85	3.46	6.38	10.69	9.13 ± 0.77
245	Bedrock (crevices)/cobble/ gravel	1	0.00	0.00	0.00	0.00	
248	Bedrock (crevices)/cobble/ shell	7	0.57	1.00	0.00	1.57	
250	Bedrock (crevices)/gravel	3	0.00	0.00	2.67	2.67	
258	Bedrock (crevices)/gravel/ shell	1	36.00	53.00	0.00	89.00	
280	Bedrock (crevices)/shell	20	0.55	1.15	3.25	4.95	
300	Boulders	8	0.25	1.75	2.25	4.25	
340	Boulders/cobble	8	3.13	3.25	3.13	9.50	
345	Boulders/cobble/gravel	1	2.00	4.00	0.00	6.00	
348	Boulders/cobble/shell	9	0.11	0.67	2.11	2.89	4.22 ± 0.70
360	Boulders/pea gravel	2	2.50	2.00	4.00	8.50	
370	Boulders/sand	1	0.00	0.00	2.00	2.00	
380	Boulders/shell	5	0.80	0.80	0.00	1.60	
384	Boulders/shell/cobble	9	0.56	0.44	0.56	1.56	
385	Boulders/shell/gravel	3	1.00	2.33	0.33	3.67	

Table 6a. Continued.

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density	Total Density By Main Substrate
400	Cobble	7	1.43	2.29	1.86	5.57	
420	Cobble/bedrock (creviced)	2	4.50	3.00	0.00	7.50	
430	Cobble/boulders	2	0.00	0.50	5.00	5.50	
438	Cobble/boulders/shell	26	2.12	2.85	2.31	7.27	7.05 ± 1.17
458	Cobble/gravel/shell	4	0.50	7.25	4.00	11.75	
480	Cobble/shell	1	0.00	6.00	0.00	6.00	
482	Cobble/shell/bedrock (creviced)	2	0.00	0.00	1.50	1.50	
500	Gravel	3	0.67	1.00	4.33	6.00	
540	Gravel/cobble	1	0.00	0.00	1.00	1.00	6.80 ± 2.97
582	Gravel/shell/bedrock (creviced)	1	0.00	0.00	15.00	15.00	
689	Pea gravel/shell/mud	4	0.00	0.00	0.00	0.00	0.00
700	Sand	1	0.00	0.00	0.00	0.00	
710	Sand/bedrock (smooth)	1	0.00	2.00	0.00	2.00	0.60 ± 0.40
760	Sand/pea gravel	1	0.00	0.00	1.00	1.00	
789	Sand/shell/mud	2	0.00	0.00	0.00	0.00	
800	Shell	1	1.00	5.00	0.00	6.00	
852	Shell/gravel/bedrock (creviced)	1	1.00	1.00	0.00	2.00	2.67 ± 1.76
890	Shell/mud	1	0.00	0.00	0.00	0.00	

Table 6b. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by substrate type in the Stephenson Islets in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD, Unknown = unmeasured, Total Density by Main Substrate = density for all urchins within the dominant substrate type).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density	Total Density By Main Substrate
100	Bedrock (smooth)	152	1.01	3.05	4.01	8.07	
130	Bedrock (smooth)/boulders	1	0.00	0.00	14.00	14.00	
135	Bedrock (smooth)/boulders/ gravel	2	1.50	2.00	0.00	3.50	7.99± 0.75
150	Bedrock (smooth)/gravel	1	2.00	4.00	0.00	6.00	
160	Bedrock (smooth)/pea gravel	2	0.00	0.50	4.00	4.50	
200	Bedrock (crevices)	129	1.81	3.93	5.91	11.65	
230	Bedrock (crevices)/boulders	2	0.00	2.00	4.50	6.50	
234	Bedrock (crevices)/boulders/ cobble	4	1.50	6.00	2.75	10.25	
240	Bedrock (crevices)/cobble	10	0.50	3.70	8.30	12.50	
245	Bedrock (crevices)/cobble/ gravel	1	0.00	0.00	0.00	0.00	11.12 ± 1.02
248	Bedrock (crevices)/cobble/ shell	6	0.67	1.17	0.00	1.83	
250	Bedrock (crevices)/gravel	3	0.00	0.00	2.67	2.67	
258	Bedrock (crevices)/gravel/ shell	1	36.00	53.00	0.00	89.00	
280	Bedrock (crevices)/shell	13	0.77	1.69	4.38	6.85	
300	Boulders	3	0.33	2.00	0.67	3.00	
340	Boulders/cobble	5	2.80	4.60	5.00	12.40	
345	Boulders/cobble/gravel	1	2.00	4.00	0.00	6.00	
348	Boulders/cobble/shell	8	0.13	0.50	2.38	3.00	4.39 ± 0.86
370	Boulders/sand	1	0.00	0.00	2.00	2.00	
380	Boulders/shell	1	4.00	4.00	0.00	8.00	
384	Boulders/shell/cobble	9	0.56	0.44	0.56	1.56	
385	Boulders/shell/gravel	3	1.00	2.33	0.33	3.67	
400	Cobble	3	1.33	2.33	3.00	6.67	
420	Cobble/bedrock (creviced)	1	2.00	1.00	0.00	3.00	
430	Cobble/boulders	1	0.00	0.00	10.00	10.00	
438	Cobble/boulders/shell	4	0.25	5.25	0.00	5.50	7.00 ± 2.00
458	Cobble/gravel/shell	4	0.50	7.25	4.00	11.75	
482	Cobble/shell/bedrock (creviced)	2	0.00	0.00	1.50	1.50	
500	Gravel	3	0.67	1.00	4.33	6.00	
540	Gravel/cobble	1	0.00	0.00	1.00	1.00	6.80 ± 2.97
582	Gravel/shell/bedrock (creviced)	1	0.00	0.00	15.00	15.00	

Table 6b. Continued.

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density	Total Density By Main Substrate
700	Sand	1	0.00	0.00	0.00	0.00	
710	Sand/bedrock (smooth)	1	0.00	2.00	0.00	2.00	1.00 ± 0.58
760	Sand/pea gravel	1	0.00	0.00	1.00	1.00	
800	Shell	1	1.00	5.00	0.00	6.00	4.00 ± 2.00
852	Shell/gravel/bedrock (creviced)	1	1.00	1.00	0.00	2.00	

Table 6c. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by substrate type at Stubbs Island in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD, Unknown = unmeasured, Total Density by Main Substrate = density for all urchins within the dominant substrate type).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density	Total Density By Main Substrate
100	Bedrock (smooth)	22	3.36	3.55	0.00	6.91	6.91 ± 2.13
200	Bedrock (crevices)	4	1.50	2.25	0.00	3.75	
234	Bedrock (crevices)/boulders/ cobble	3	11.67	13.00	0.00	24.67	10.09 ± 3.15
240	Bedrock (crevices)/cobble	3	2.00	2.67	0.00	4.67	
280	Bedrock (crevices)/shell	1	0.00	0.00	8.00	8.00	

Table 6d. Sample mean densities (urchins/m^2) of green sea urchins of legal size, sublegal size, unknown size and all sizes (total) by substrate type in the Plumper Islands in the October, 2006 survey. (Legal = ≥ 55 mm TD, Sublegal = < 55 mm TD, Unknown = unmeasured, Total Density by Main Substrate = density for all urchins within the dominant substrate type).

Code	Substrate Type	Number of Quadrats	Legal Density	Sublegal Density	Unknown Density	Total Density	Total Density By Main Substrate
100	Bedrock (smooth)	10	1.10	1.90	1.80	4.80	
120	Bedrock (smooth)/bedrock (crevices)	1	0.00	0.00	0.00	0.00	
123	Bedrock (smooth)/bedrock (crevices)/boulders	2	0.50	2.50	0.00	3.00	3.65 ± 1.25
134	Bedrock (smooth)/boulders/ cobble	1	3.00	5.00	0.00	8.00	
138	Bedrock (smooth)/boulders/ shell	1	0.00	0.00	0.00	0.00	
153	Bedrock (smooth)/gravel/ boulders	2	0.00	0.00	0.00	0.00	
200	Bedrock (crevices)	38	1.13	3.16	0.00	4.29	
230	Bedrock (crevices)/boulders	8	2.00	0.88	2.25	5.13	
234	Bedrock (crevices)/boulders/ cobble	1	1.00	2.00	0.00	3.00	
235	Bedrock (crevices)/boulders/ gravel	1	0.00	0.00	0.00	0.00	3.55 ± 0.71
238	Bedrock (crevices)/boulders/ shell	7	0.14	0.71	0.71	1.57	
248	Bedrock (crevices)/cobble/ shell	1	0.00	0.00	0.00	0.00	
280	Bedrock (crevices)/shell	6	0.17	0.17	0.00	0.33	
300	Boulders	5	0.20	1.60	3.20	5.00	
340	Boulders/cobble	3	3.67	1.00	0.00	4.67	
348	Boulders/cobble/shell	1	0.00	2.00	0.00	2.00	3.87 ± 1.26
360	Boulders/pea gravel	2	2.50	2.00	4.00	8.50	
380	Boulders/shell	4	0.00	0.00	0.00	0.00	
400	Cobble	4	1.50	2.25	1.00	4.75	
420	Cobble/bedrock (creviced)	1	7.00	5.00	0.00	12.00	
430	Cobble/boulders	1	0.00	1.00	0.00	1.00	7.07 ± 1.47
438	Cobble/boulders/shell	22	2.45	2.41	2.73	7.59	
480	Cobble/shell	1	0.00	6.00	0.00	6.00	
689	Pea gravel/shell/mud	4	0.00	0.00	0.00	0.00	0.00
789	Sand/shell/mud	2	0.00	0.00	0.00	0.00	0.00
890	Shell/mud	1	0.00	0.00	0.00	0.00	0.00

Table 7. Summary results of measurements taken during green urchin dissections in the October, 2006 survey. (Legal ≥ 55 mm TD, Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD. SE = Standard Error; Gutted Weight = stomach and contents removed; Gonad Texture: 0=unknown or no sample, 1=orange/yellow, 2=yellow with other colours, 3=brown/red; Gonad Texture: 0=unknown or no sample, 1=firm, 2=semi-firm, 3=flimsy; Sex: 1=male, 2=female, 3=juvenile or unknown. Sample Size 1 is for test height, TD and total wet weight. Sample Size 2 is for all other calculations).

Summary Information			LOCATION								
			STEPHENSON ISLETS			STUBBS ISLAND			PLUMPER ISLANDS		
			Legal	Sublegal-mature	Sublegal-immature	Legal	Sublegal-mature	Sublegal-immature	Legal	Sublegal-mature	Sublegal-immature
Sample Size 1			93	88	1	11	8	0	46	33	1
Mean Test Height (mm) ± SE			34.3 (± 0.4)	24.4 (± 0.5)	8.0	40.0 (± 2.2)	28.6 (± 0.9)	-	33.9 (± 0.6)	22.0 (± 0.8)	13.0
Mean Test Diameter (mm) ± SE			63.4 (± 0.6)	44.2 (± 0.8)	12.0	73.3 (± 3.1)	50.6 (± 0.8)	-	63.7 (± 0.9)	41.1 (± 1.5)	22.0
Mean Total Wet Weight (g) ± SE			76.8 (± 2.4)	29.2 (± 1.3)	0.8	111.9 (± 12.8)	39.1 (± 2.5)	-	81.6 (± 3.6)	24.3 (± 2.4)	3.6
Sample Size 2			34	47	0	5	4	0	17	20	1
Mean Drained Weight (g) ± SE			55.2 (± 2.3)	23.1 (± 1.6)	-	74.6 (± 10.3)	30.5 (± 2.5)	-	61.6 (± 4.9)	20.3 (± 2.8)	3.2
Mean Gutted Weight (g) ± SE			40.2 (± 1.9)	16.7 (± 1.2)	-	57.6 (± 8.3)	22.4 (± 2.3)	-	42.1 (± 3.7)	13.9 (± 2.0)	2.0
Mean Stomach and Contents Weight (g) ± SE			14.9 (± 0.7)	6.2 (± 0.5)	-	17.0 (± 2.2)	8.1 (± 0.2)	-	16.1 (± 3.1)	6.4 (± 0.8)	1.2
Sex	% Male		18	23	-	100	25	-	17	10	0
	% Female		26	30	-	0	50	-	22	10	0
	% Unknown		56	47	-	0	25	-	61	80	100
Gonad	Mean Weight (g) ± SE		7.6 (± 0.9)	3.4 (± 0.4)	-	15.1 (± 3.1)	5.0 (± 1.1)	-	9.1 (± 1.2)	2.3 (± 0.7)	0.0
	Colour Proportion	0	0	0.02	-	0	0	-	0	0.10	1.00
		1	0.38	0.64	-	0	0.75	-	0.50	0.35	0
		2	0.29	0.11	-	0.80	0	-	0.28	0.10	0
		3	0.26	0	-	0	0	-	0	0	0
		4	0.06	0.23	-	0.20	0.25	-	0.22	0.45	0
	Texture Proportion	0	0	0.02	-	0	0	-	0	0.10	1.00
		1	0.65	0.21	-	0.20	0	-	0.72	0.20	0
		2	0.29	0.77	-	0.80	0.75	-	0.28	0.65	0
		3	0.06	0	-	0	0.25	-	0	0.05	0

Table 8. Comparisons of percentage of highest roe quality (roe with best colour and texture) and mean roe recovery rates (total gonad weight divided by total drained weight) at Stephenson Islets, Stubbs Island and Plumper Islands in October, 2006. (Sample size = total number of urchins with roe).

Location	Sample Size		Highest Quality Roe		Mean Roe Recovery Rates	
	Legal	Sublegal	Legal	Sublegal	Legal	Sublegal
Stephenson Islets October, 2006	34	46	32.4%	15.2%	13.8%	14.7%
Stubbs Island October, 2006	5	4	0.0%	0.0%	20.3%	16.3%
Plumper Islands October, 2006	18	18	33.3%	11.1%	15.0%	11.9%

Table 9. Calculated total abundance (number) and biomass (tonnes) of green sea urchins by site and size category in October, 2006 (incorporates estimates from unknowns). (Legal ≥ 55 mm test diameter (TD), Sublegal-mature 25 mm ≤ TD < 55 mm, Sublegal-immature < 25 mm TD. Biomass estimates were calculated using TD-weight relationships determined from October, 2006 lab measurements for each of the three sites separately, and applied to the field survey TD measurements).

Size Category	Stephenson Islets	Stubbs Island	Plumper Islands
Number of Legal-sized	1,245,304 ± 323,017	74,242 ± 54,678	383,560 ± 85,996
Number of Sublegal-mature	3,004,946 ± 507,018	80,182 ± 62,094	548,680 ± 174,788
Number of Sublegal-immature	93,746 ± 26,752	1,782 ± 864	5,160 ± 5,780
Number of all sizes	4,342,730 ± 665,998	156,206 ± 115,908	937,400 ± 179,695
Biomass of Legal-size (t)	87.00 ± 22.58	6.12 ± 4.52	25.29 ± 5.69
Biomass of Sublegal-mature (t)	85.71 ± 14.47	2.30 ± 1.78	14.55 ± 4.64
Biomass of Sublegal-immature (t)	0.30 ± 0.09	0.005 ± 0.003	0.013 ± 0.014
Total Biomass (t)	173.01 ± 26.82	8.42 ± 4.85	39.85 ± 7.34

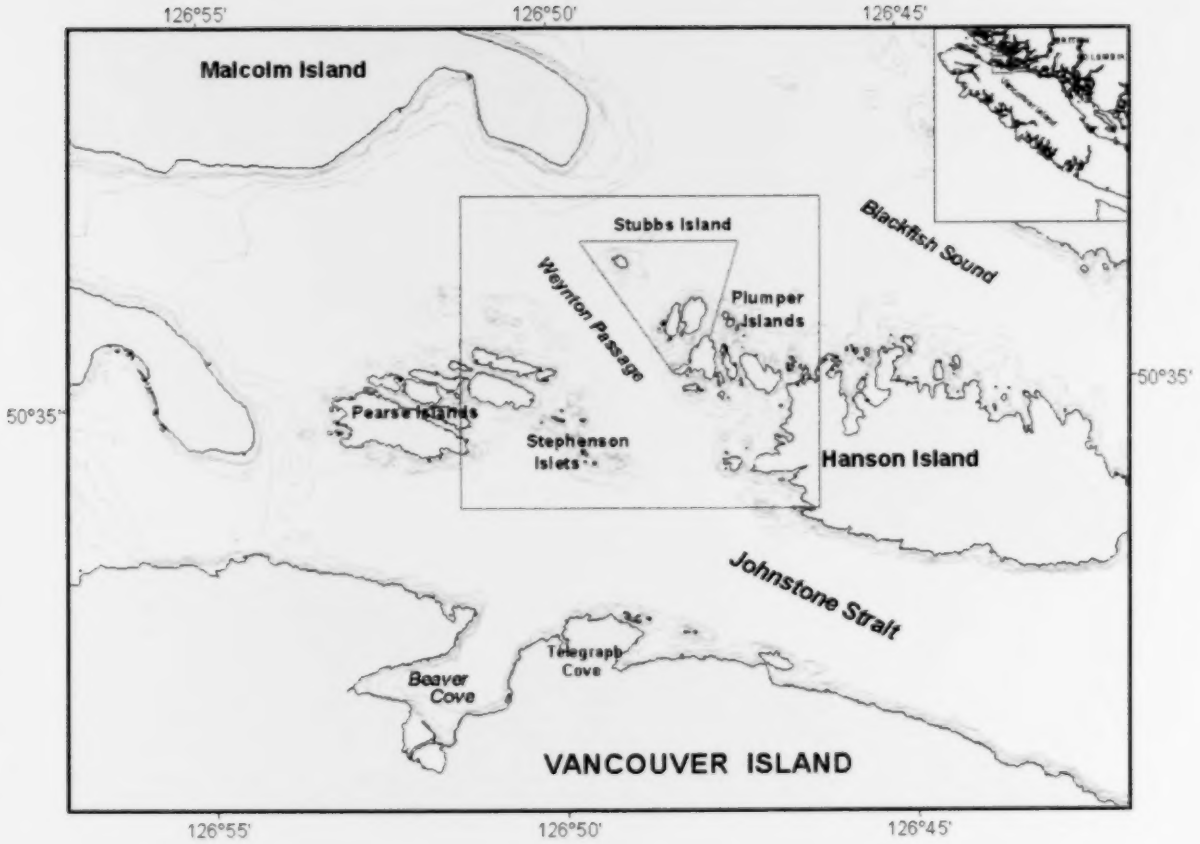

Fig. 1a. Site locations for the October, 2006 green urchin survey (Stephenson Islets, Stubbs Island and the Plumper Islands). The red border represents the boundaries of the research closure area. No commercial fishing may occur within these boundaries.

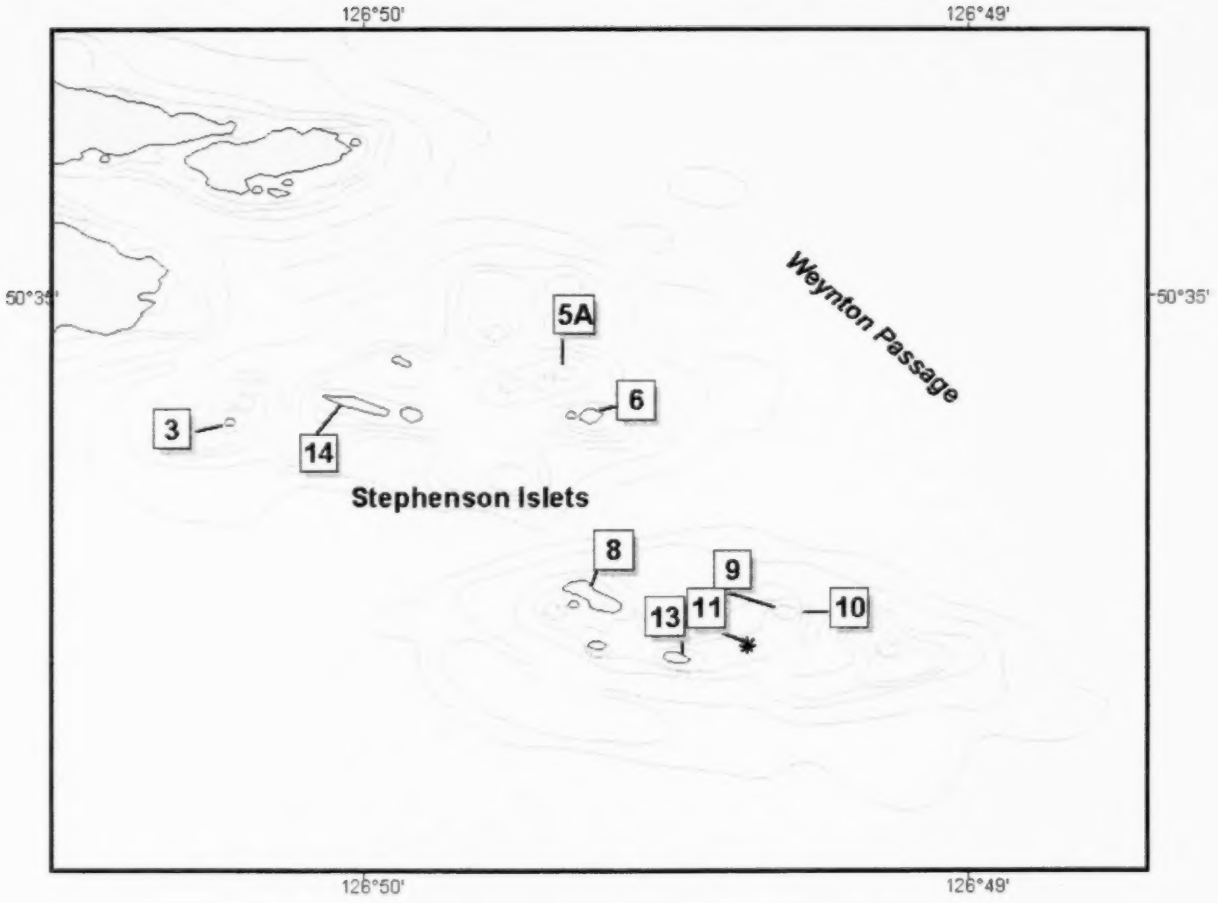

Fig. 1b. Transect locations (black lines) for the October, 2006 green sea urchin survey, Stephenson Islets.

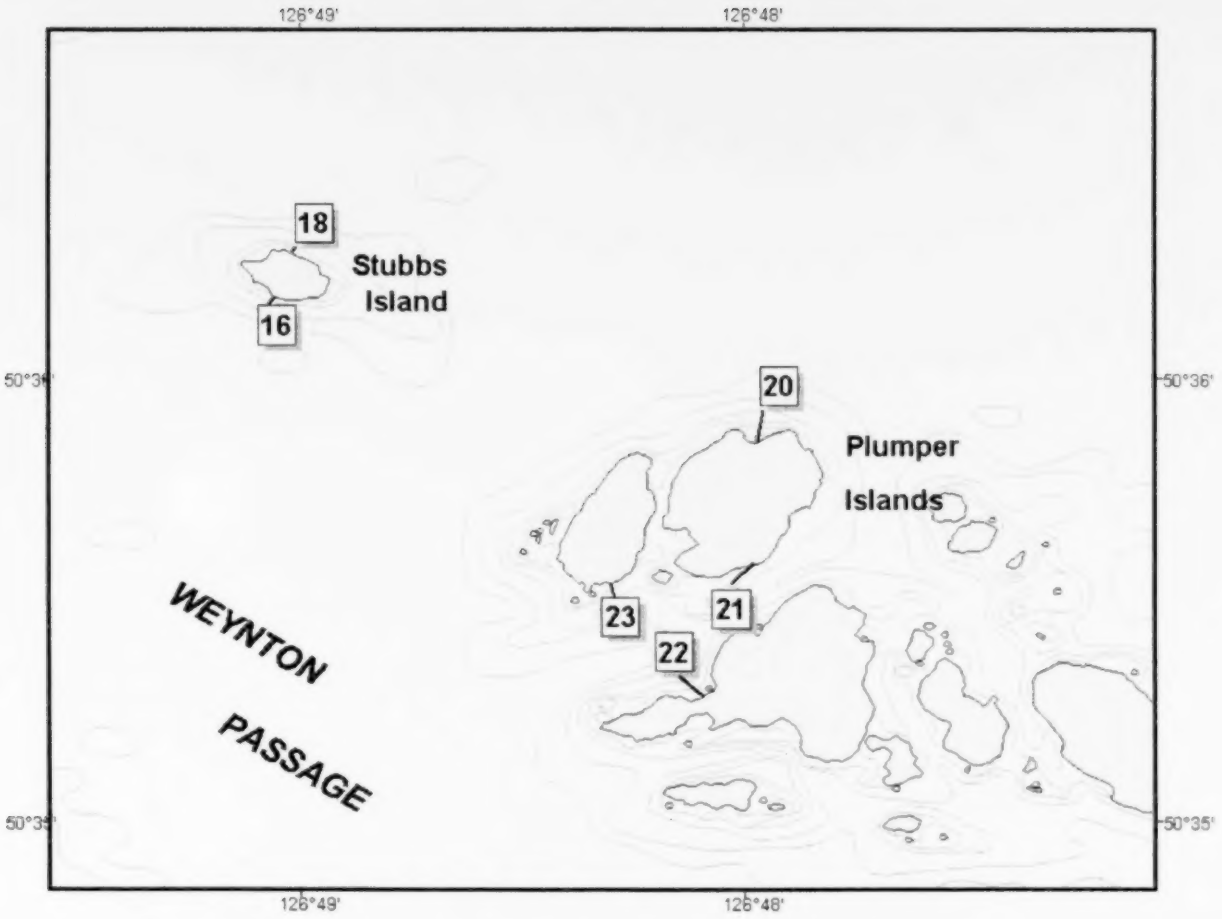

Fig. 1c. Transect locations (black lines) for the October, 2006 green sea urchin survey, Stubbs Island and the Plumper Islands.

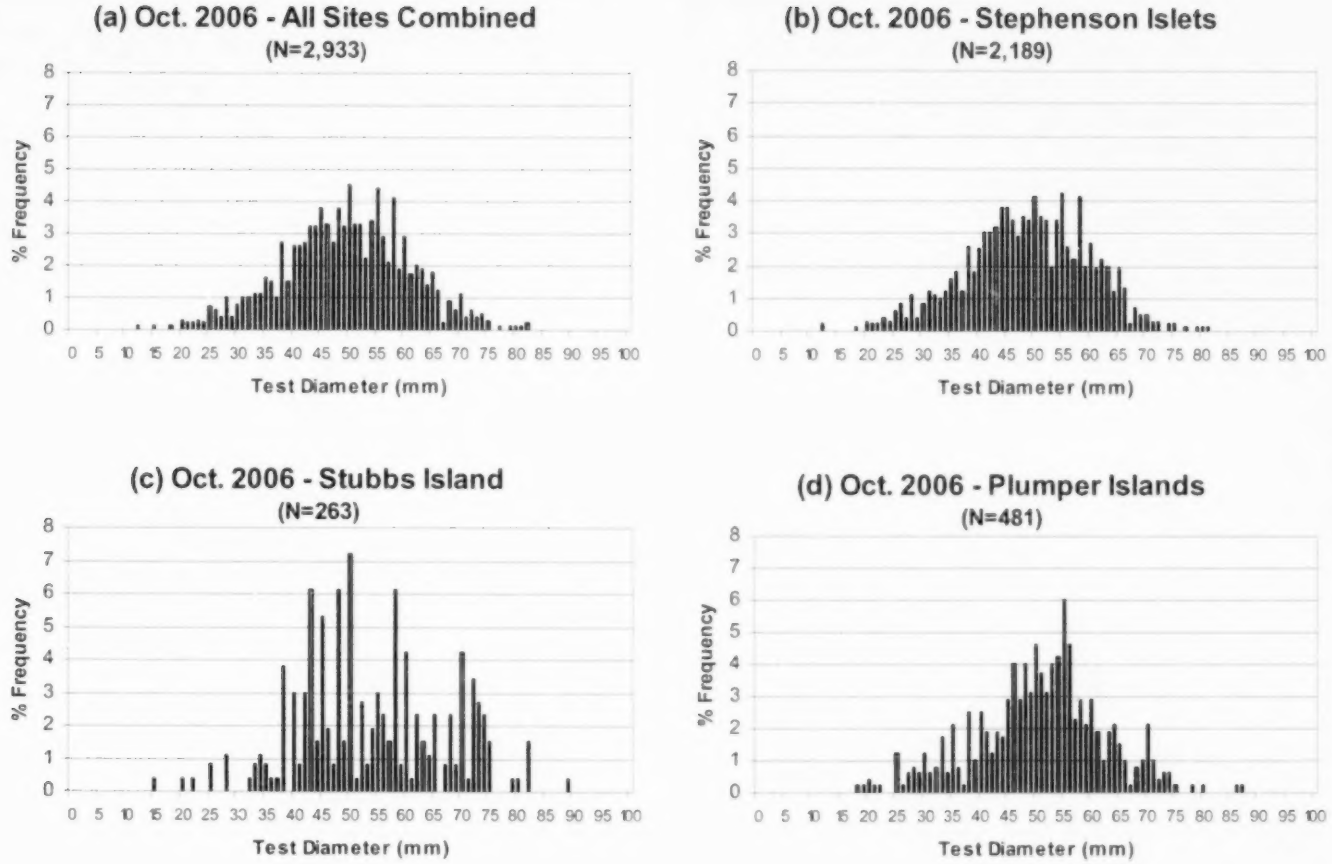

Fig. 2. Size (test diameter in millimeters) distributions of green sea urchins collected in October, 2006 from (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. Note the fishery minimum size limit is 55 mm.

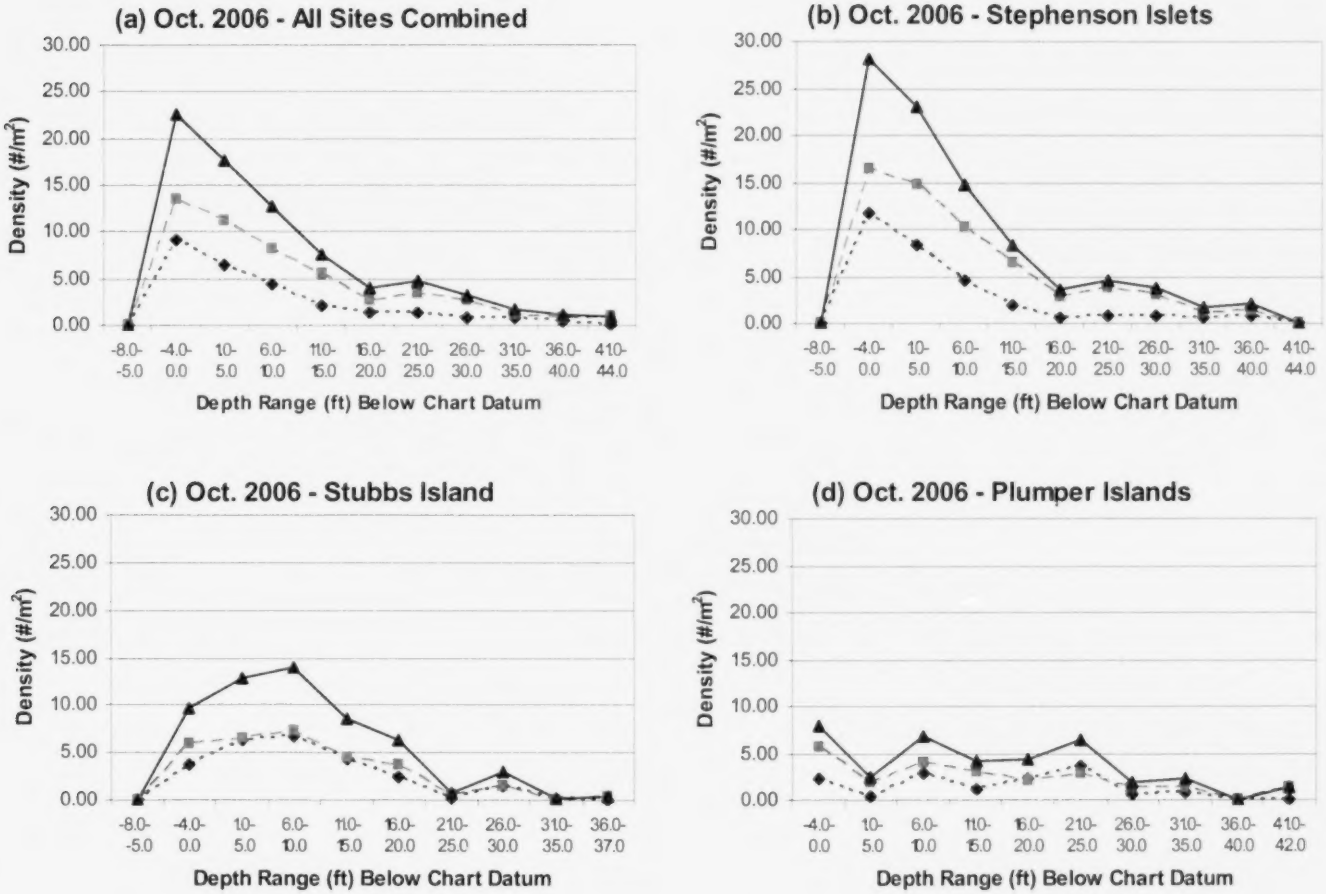

Fig. 3. October, 2006 mean densities (number per square meter) of green sea urchins of all sizes (total = triangles), legal size (diamonds), and sublegal size (squares) by depth range (feet) below Chart Datum from: (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands.

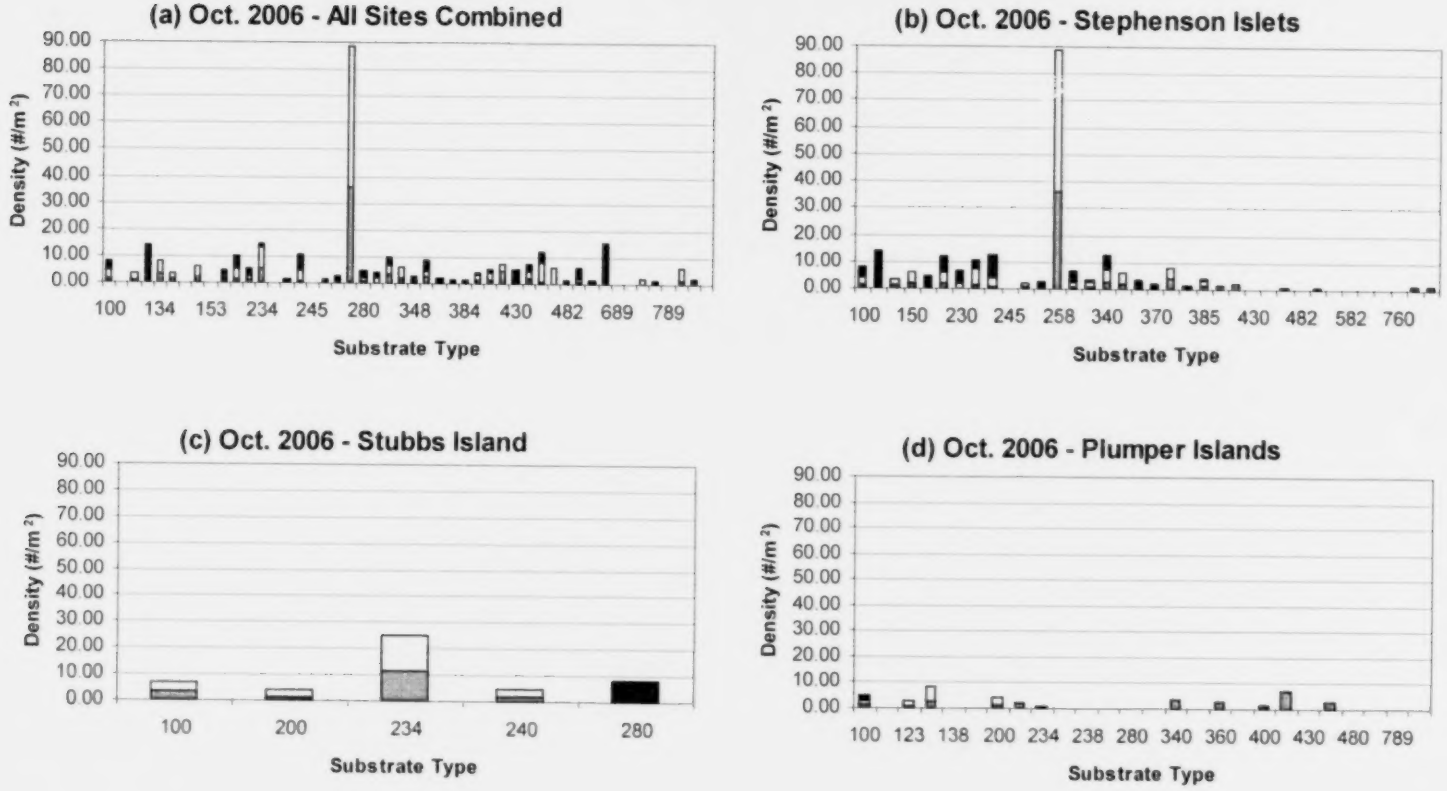

Fig. 4. October, 2006 mean densities (number per square meter) of green sea urchins of legal size (grey), sublegal size (white) and unknown size (black), by substrate type from: (a) all sites combined; (b) Stephenson Islets; (c) Stubbs Island; and (d) Plumper Islands. See Tables 8a-d for the keys to the substrate codes.

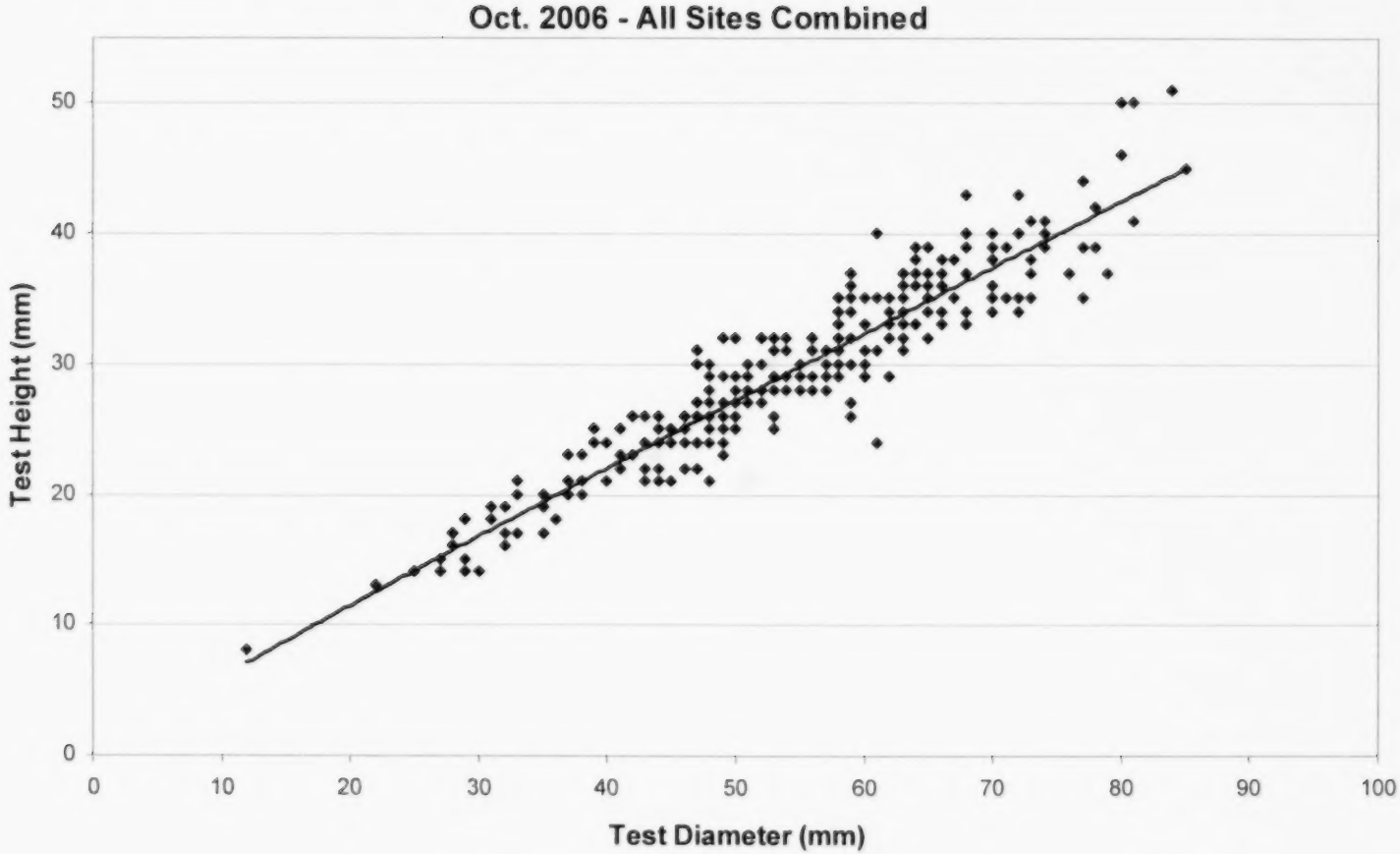

Fig. 5. Relationship between green sea urchin test diameter (TD, in millimeters) and test height (millimeters) in October, 2006, for all sites combined: TEST HEIGHT (mm) = $0.6676(TD^{0.9474})$, $R^2 = 0.9106$, n=281.

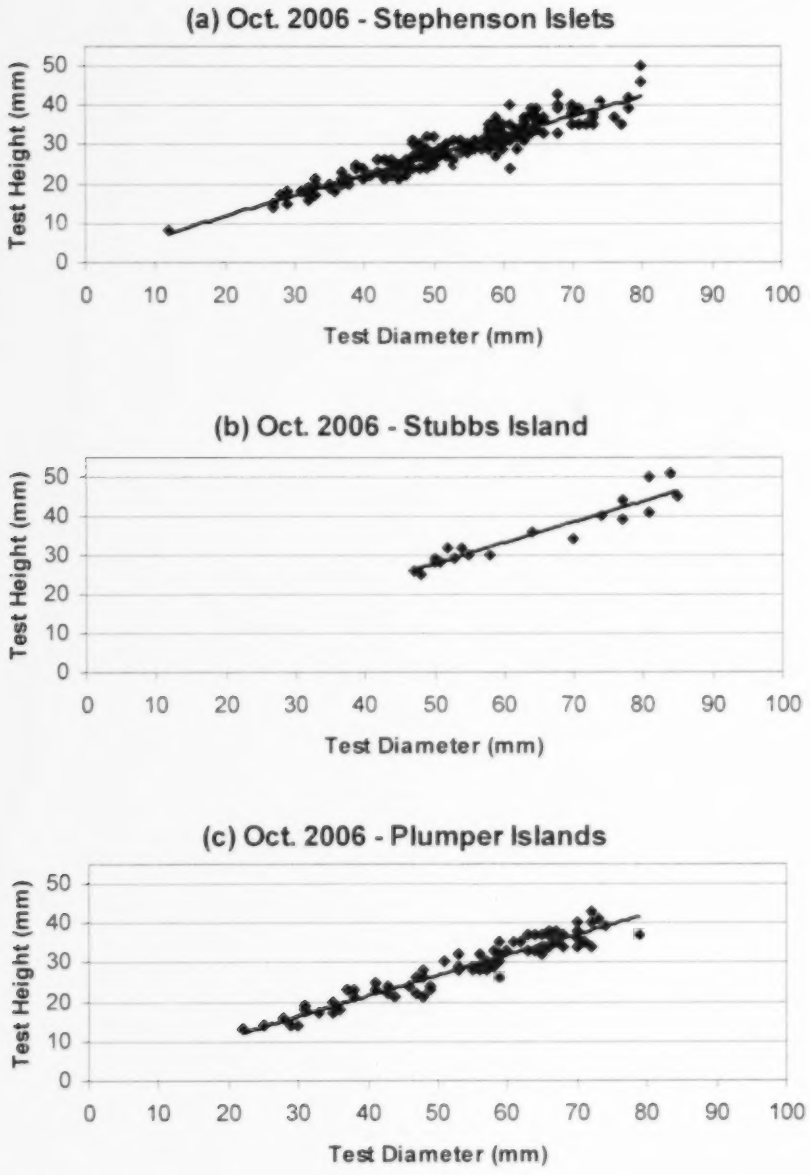
(a) Oct. 2006 - Stephenson Islets
Test Height (mm)
Test Diameter (mm)
(b) Oct. 2006 - Stubbs Island
Test Height (mm)
Test Diameter (mm)
(c) Oct. 2006 - Plumper Islands
Test Height (mm)
Test Diameter (mm)

Fig. 6. Relationships between green sea urchin test diameter (TD, in millimeters) and test height (millimeters) calculated in October, 2006 for:
(a) Stephenson Islets (TEST HEIGHT (mm) = $0.7392(TD^{0.9229})$, $R^2 = 0.9015$, n=182);
(b) Stubbs Island (TEST HEIGHT (mm) = $0.6316(TD^{0.9673})$, $R^2 = 0.9046$, n=19);
(c) Plumper Islands (TEST HEIGHT (mm) = $0.5886(TD^{0.9750})$, $R^2 = 0.9250$, n=80).

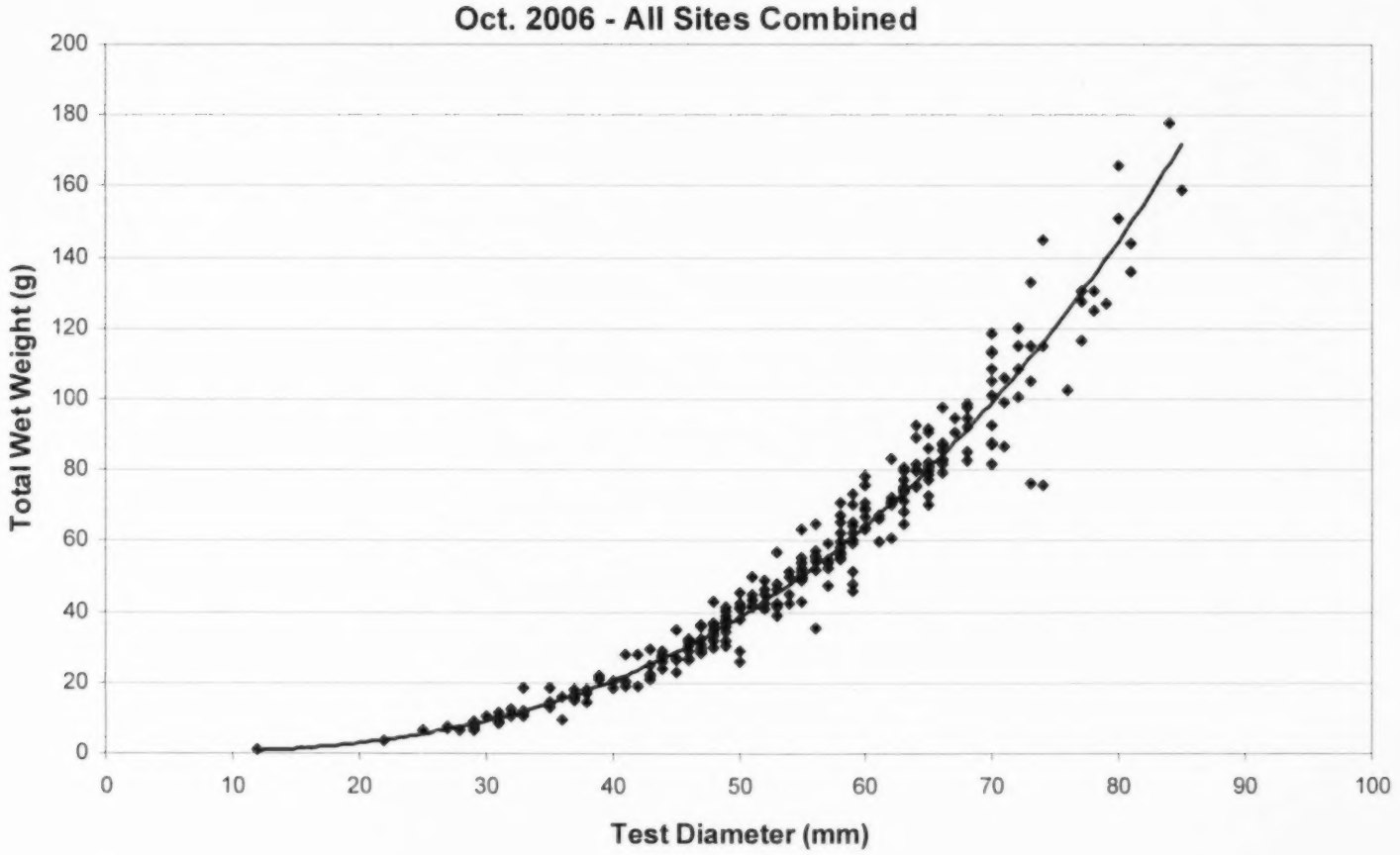

Fig. 7. Relationship between green sea urchin test diameter (TD, in millimeters) and total wet weight (grams) in October, 2006, for all sites combined: TOTAL WET WEIGHT (g) = $0.0006(TD^{2.8232})$, $R^2 = 0.9759$, n=281.

.

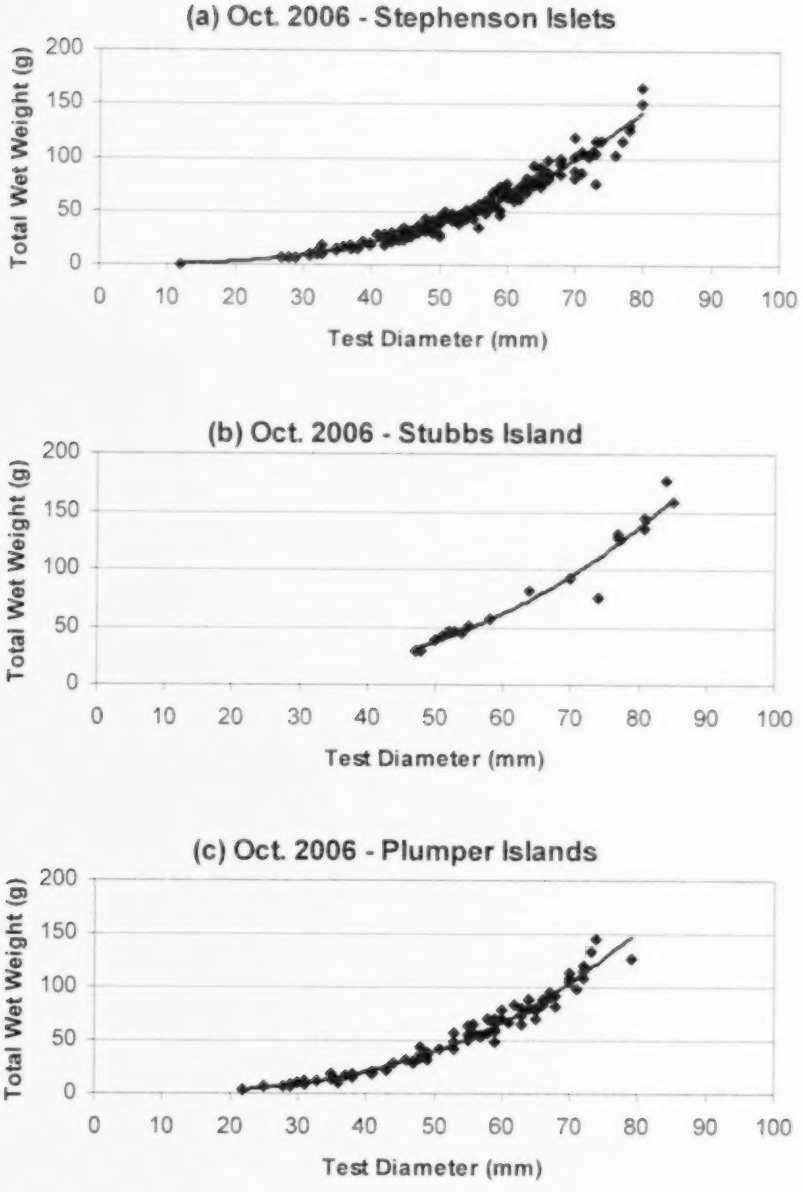

Fig. 8. Relationships between green sea urchin test diameter (TD, in millimeters) and total wet weight (grams) calculated in October, 2006 for:
(a) Stephenson Islets (TOTAL WET WEIGHT (g) = $0.0007(TD^{2.7955})$, $R^2 = 0.9750$, n=182);
(b) Stubbs Island (TOTAL WET WEIGHT (g) = $0.0008(TD^{2.7536})$, $R^2 = 0.9669$, n=19);
(c) Plumper Islands (TOTAL WET WEIGHT (g) = $0.0004(TD^{2.9076})$, $R^2 = 0.9790$, n=80).
.

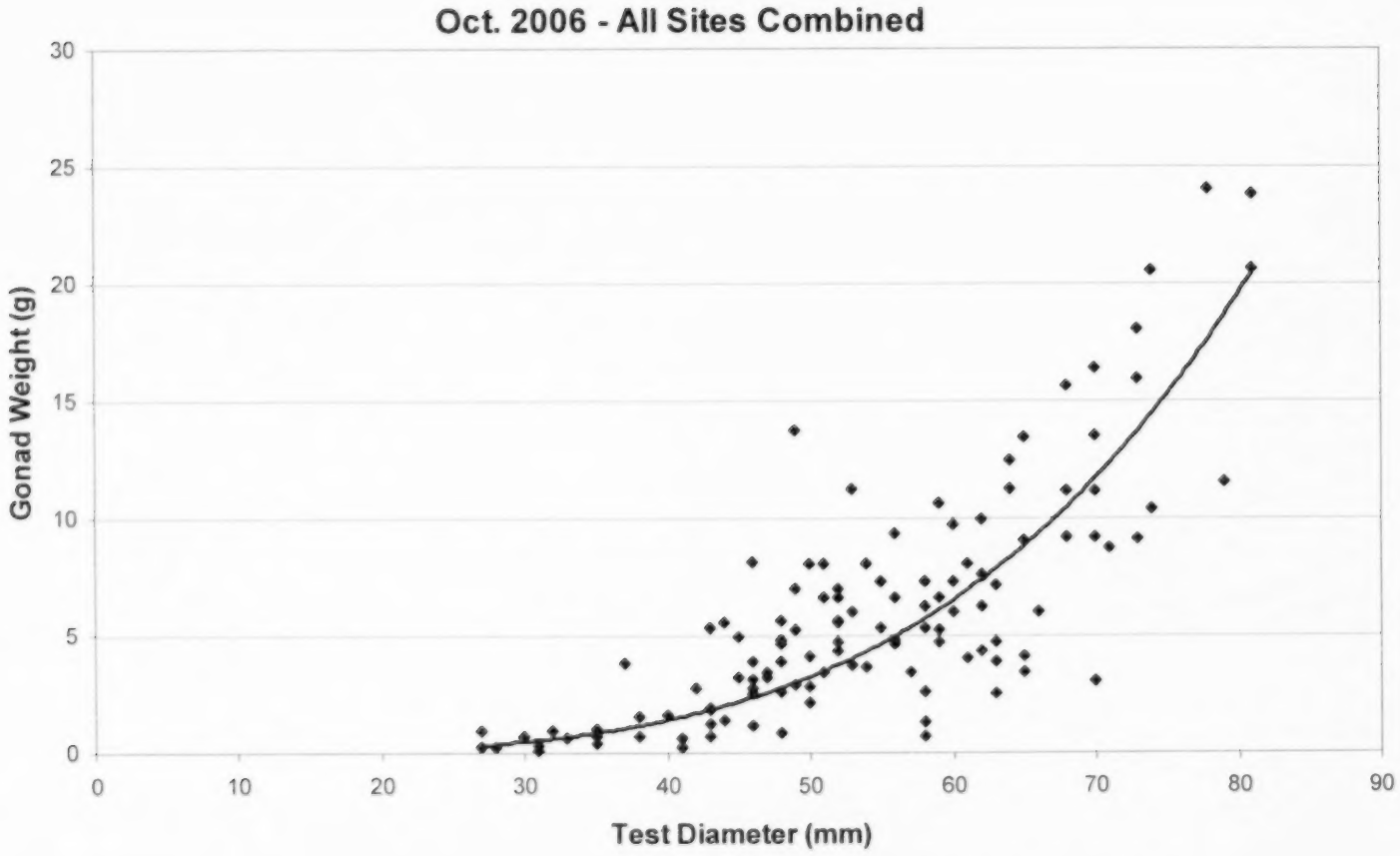

Fig. 9. Relationship between green sea urchin test diameter (TD, in millimeters) and gonad weight (grams) in October, 2006, calculated from all sites combined: GONAD WEIGHT (g) = $1 \times 10^{-6}(TD^{3.8280})$; $R^2 = 0.6841$, n = 123.

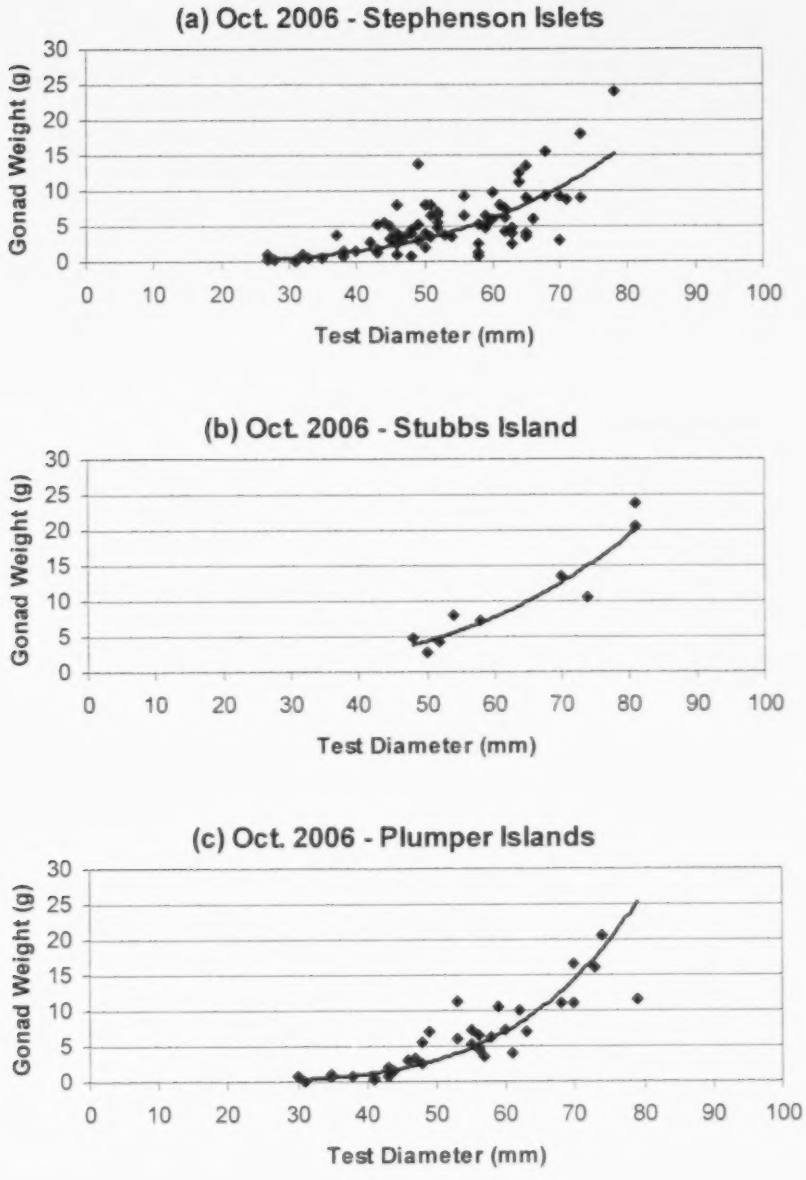
(a) Oct. 2006 - Stephenson Islets
Gonad Weight (g)
Test Diameter (mm)
(b) Oct. 2006 - Stubbs Island
Gonad Weight (g)
Test Diameter (mm)
(c) Oct. 2006 - Plumper Islands
Gonad Weight (g)
Test Diameter (mm)

Fig. 10. Relationships between green sea urchin test diameter (TD, in millimeters) and gonad weight (grams) calculated in October, 2006 for:
(a) Stephenson Islets (GONAD WEIGHT (g) = 4×10^{-6} ($TD^{3.4779}$), $R^2 = 0.6166$, n=79);
(b) Stubbs Island (GONAD WEIGHT (g) = 2×10^{-5} ($TD^{3.1739}$), $R^2 = 0.8622$, n=9);
(c) Plumper Islands (GONAD WEIGHT (g) = 4×10^{-8} ($TD^{4.6280}$), $R^2 = 0.7863$, n=35).